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United States Patent [19]

Jia

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[45] Date of Patent: Apr. 15, 1997

[54] **CONTRACTING/EXPANDING SELF-SEALING CRYOGENIC TUBE SEALS**

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[73] Assignee: **Florida Atlantic University**, Boca Raton, Fla.

[21] Appl. No.: **487,348**

[22] Filed: **Jun. 7, 1995**

Related U.S. Application Data

[62] Division of Ser. No. 71,418, Jun. 1, 1993.

[51] **Int. Cl.**^{6} **F16J 15/08**

[52] **U.S. Cl.** .... **277/26**; 277/170; 277/207 A; 277/236; 285/332.2; 285/341; 285/369; 285/904; 285/917

[58] **Field of Search** .... 277/26, 170, 207 A, 277/236; 285/187, 328, 330, 332, 332.2, 341, 369, 904, 917

[56] **References Cited**

U.S. PATENT DOCUMENTS

1,567,813	12/1925	Oleson	285/917
2,766,829	10/1956	Watts et al.	285/140
3,056,615	10/1962	Breitenstein	285/187
3,093,398	6/1963	Fawcett et al.	285/187
3,210,098	10/1965	Watts	285/187
3,281,135	10/1966	Boron	285/187
3,301,577	1/1967	Latham	285/187
3,411,812	11/1968	Prince et al.	285/187
3,630,533	12/1971	Butler et al.	277/153
3,632,143	1/1972	Lessmann	285/187
4,072,245	2/1978	Sloan, Jr.	277/206 R
4,349,203	9/1982	Schulke	285/187
4,602,809	7/1986	Ross et al.	285/904
4,813,342	3/1989	Schneider et al.	277/26
4,854,597	8/1989	Leigh	277/207 A
4,865,331	9/1989	Porter	277/26
5,355,908	10/1994	Berger et al.	285/917
5,466,018	11/1995	Stobbart	285/917

OTHER PUBLICATIONS

Handbook of Chemistry and Physics, Thirty–Third Ed Copyright, 1914–1951, by Chemical Rubber Publishing Co.

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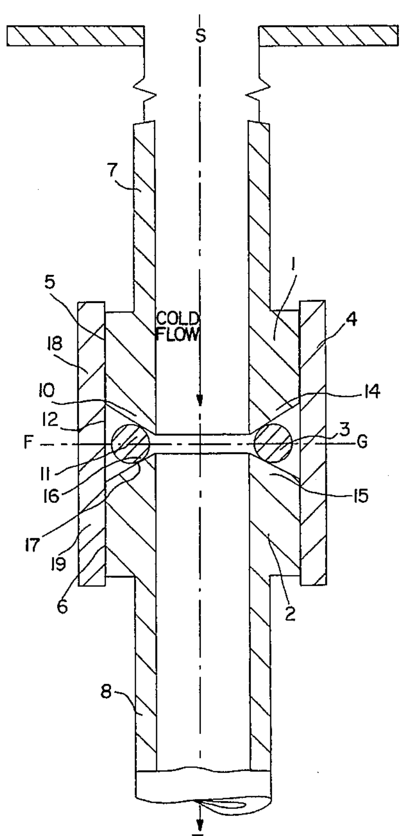
Attorney, Agent, or Firm—Saliwanchik, Lloyd & Saliwanchik

[57] **ABSTRACT**

Contracting/expanding self-sealing cryogenic tube seals are disclosed which use the different properties of thermal contraction and expansion of selected dissimilar materials in accord with certain design criteria to yield self-tightening seals via sloped-surface sealing. The seals of the subject invention are reusable, simple to assemble, adaptable to a wide variety of cryogenic applications.

10 Claims, 12 Drawing Sheets



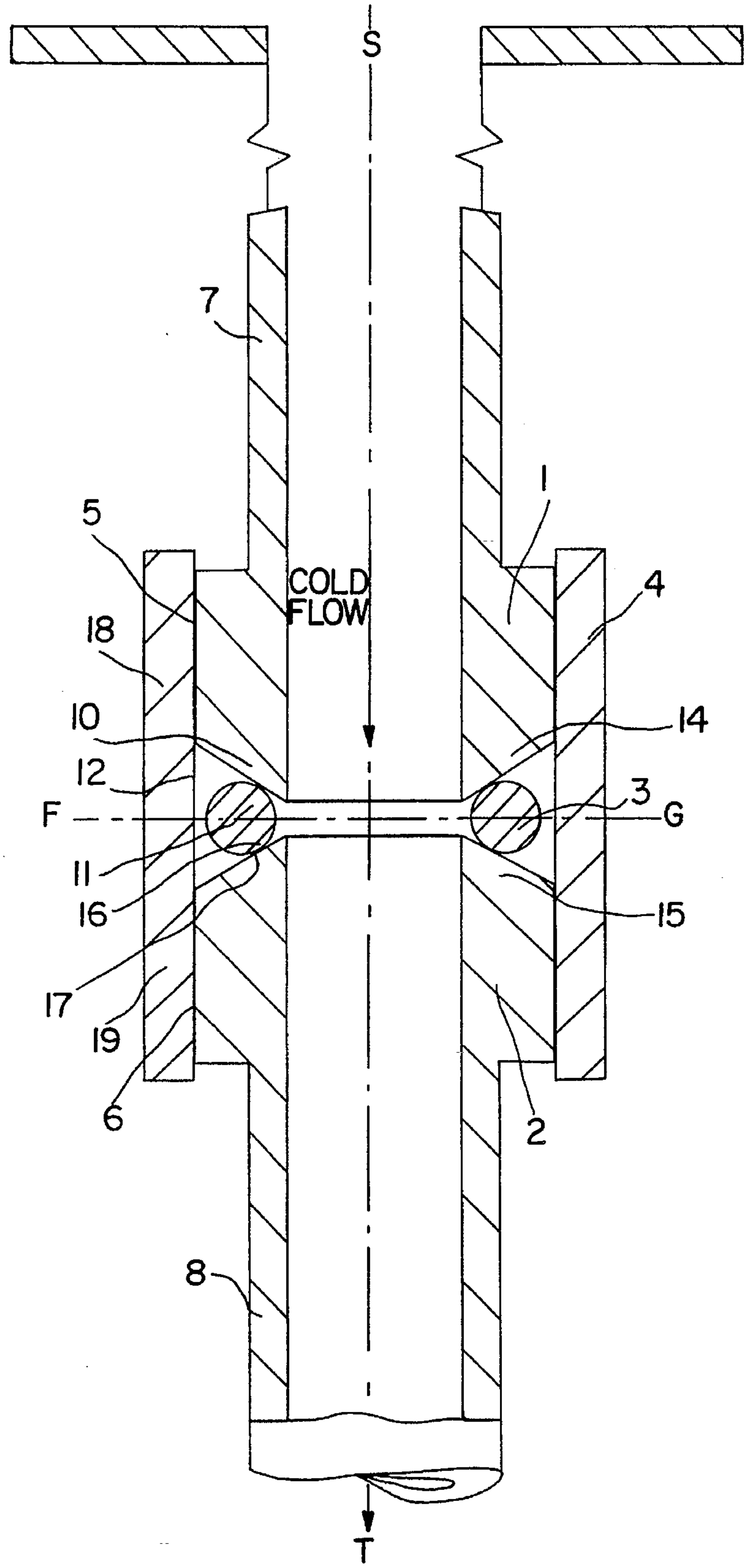


FIG. 1

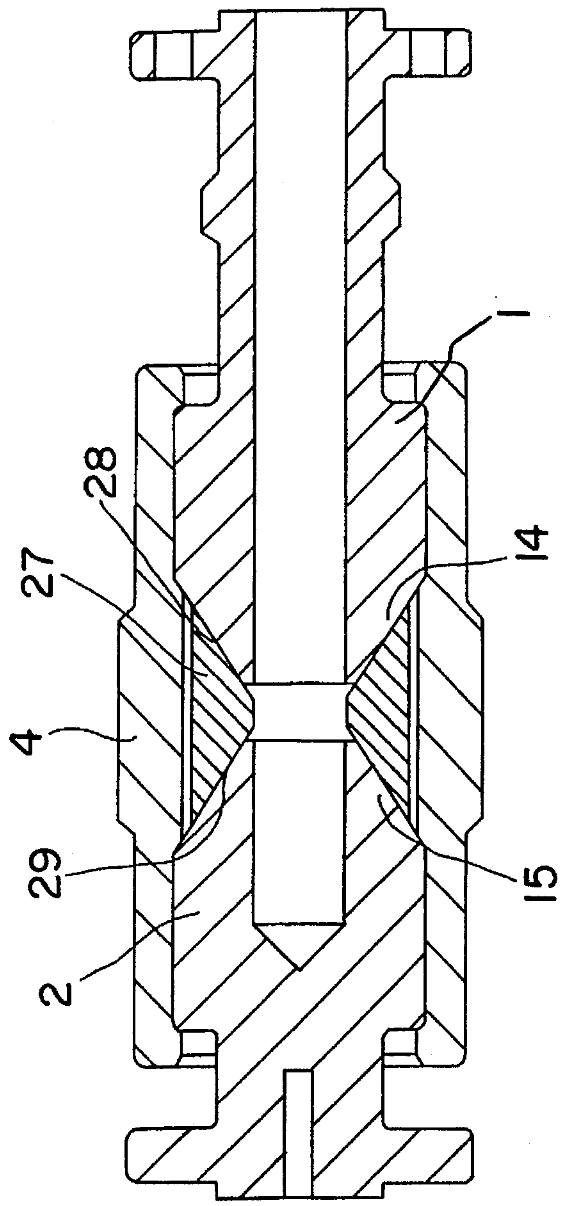


FIG. 2B

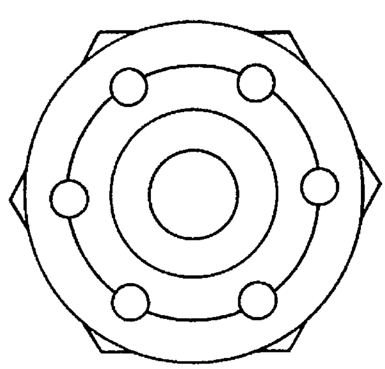


FIG. 2A

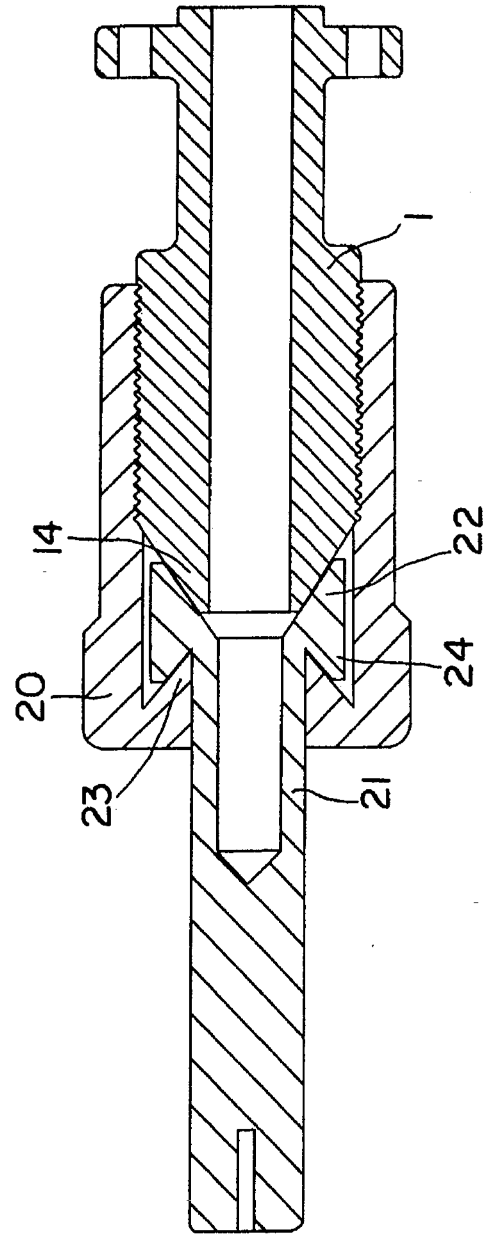


FIG. 3B

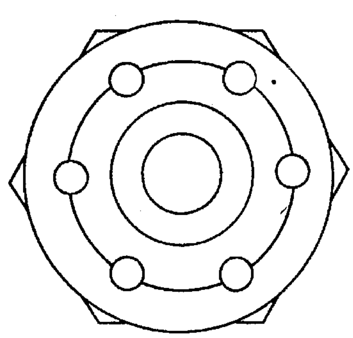


FIG. 3A

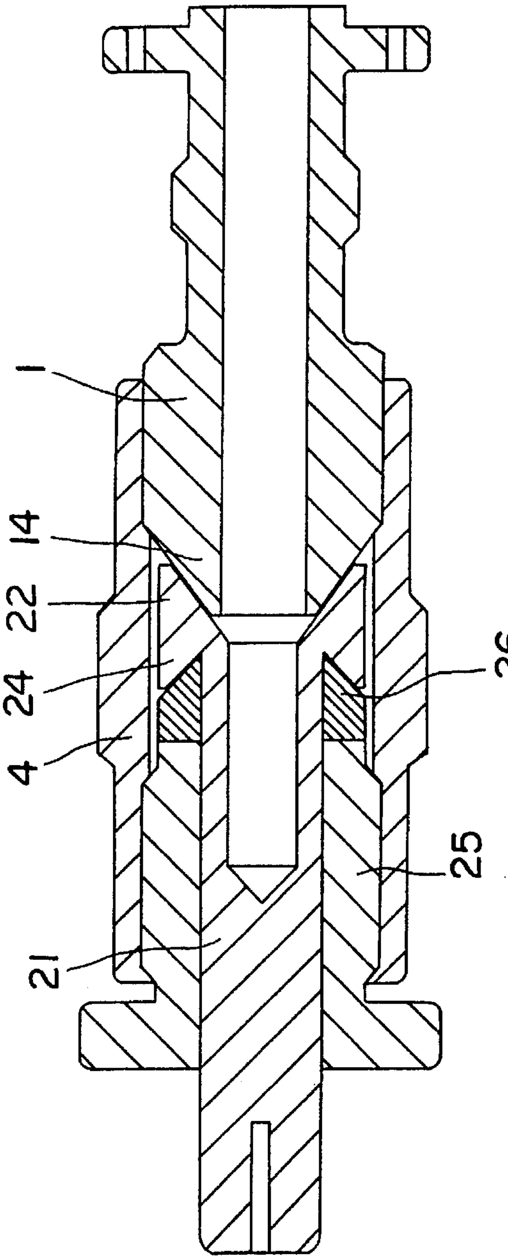


FIG.4B

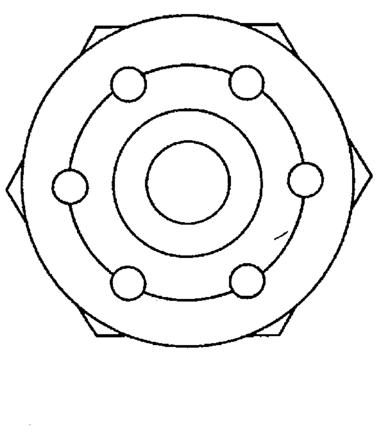
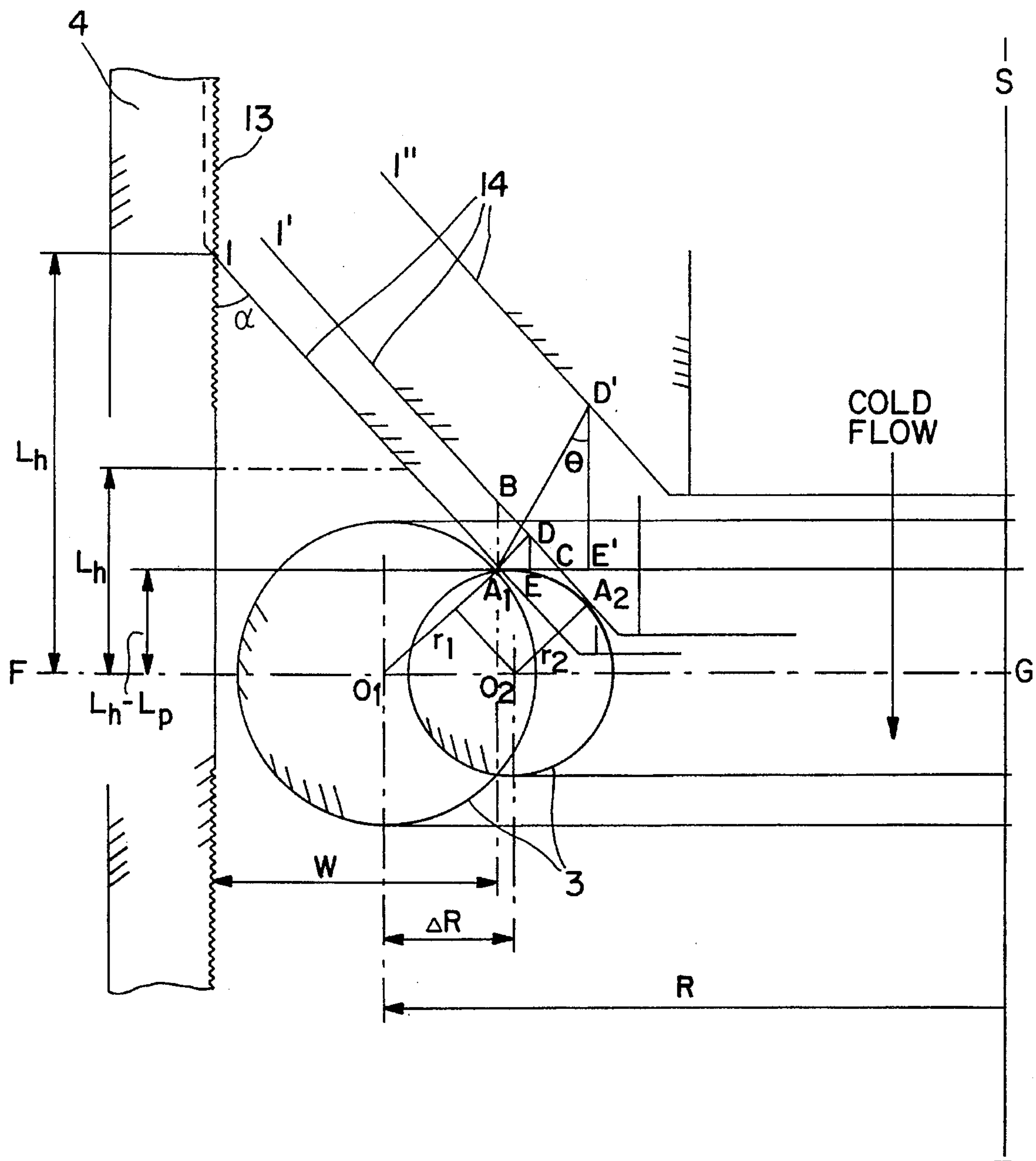


FIG.4A



4
13
1''
14
1'
1
α
S
COLD
FLOW
D'
θ
L_h
L_h
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D
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E'
A_1
E
A_2
r_1
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F
O_1
O_2
G
L_h-L_p
W
3
ΔR
R
T

FIG. 5

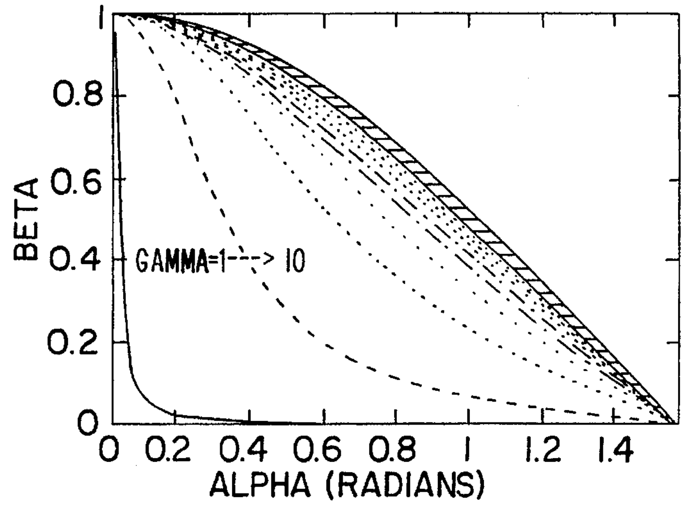

FIG.6A

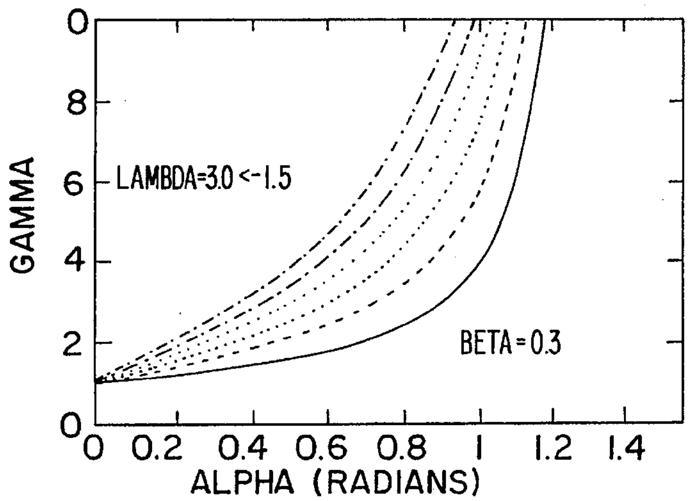

FIG.6B

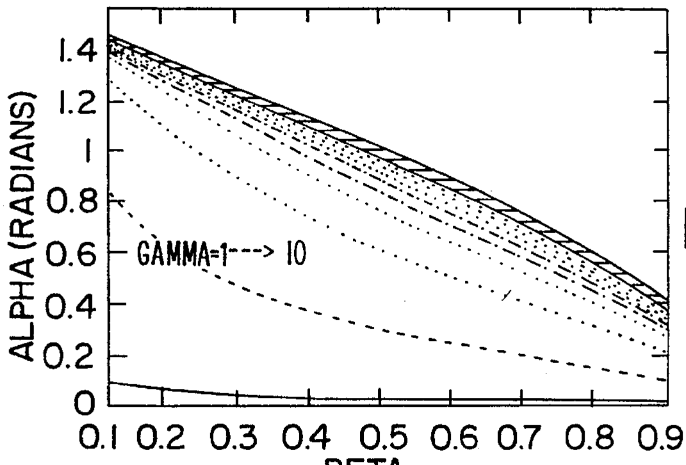

FIG.6C

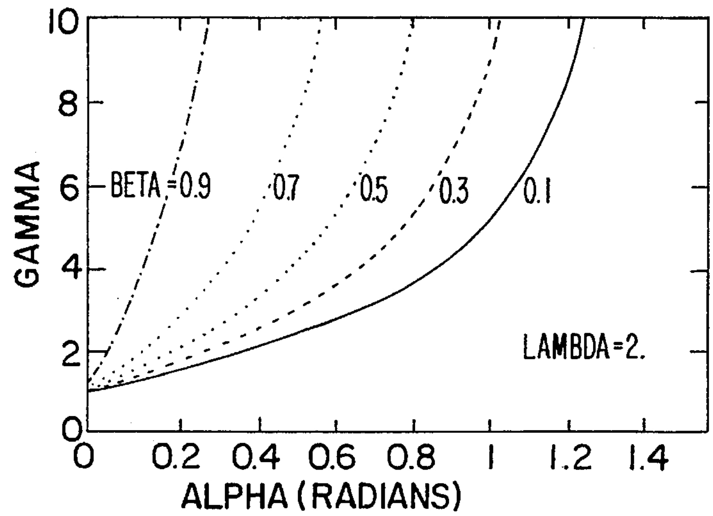

FIG.6D

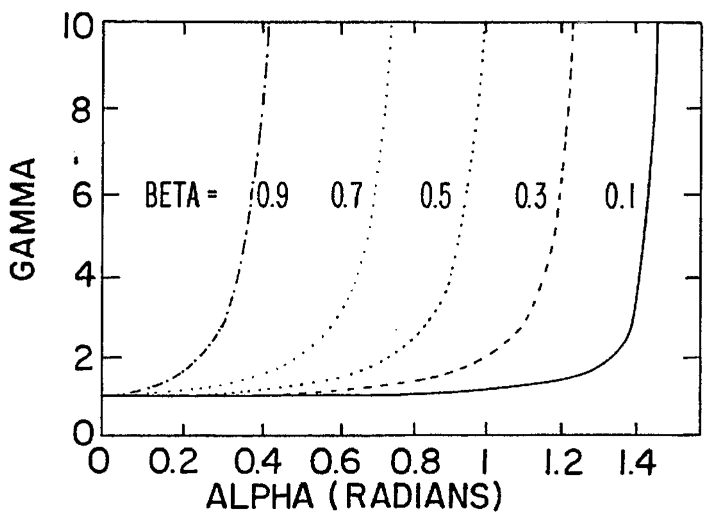

FIG.6E

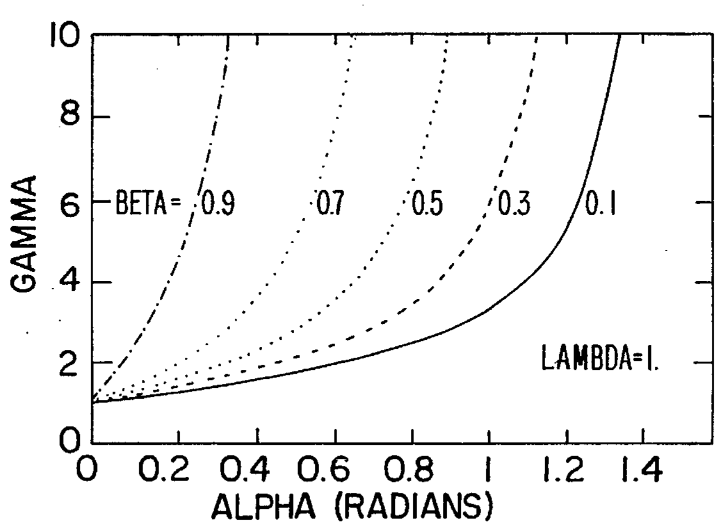

FIG.6F

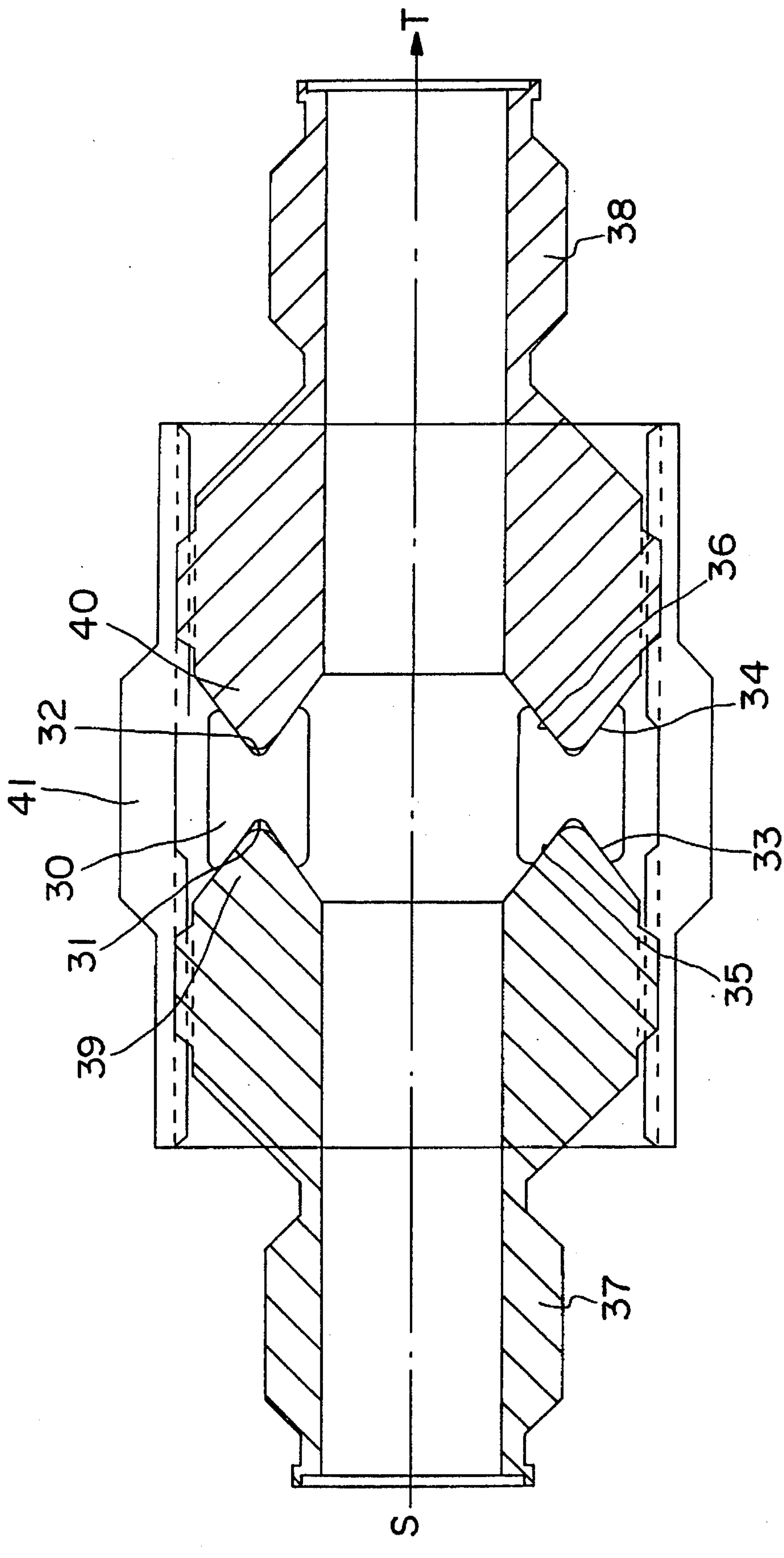

FIG. 7

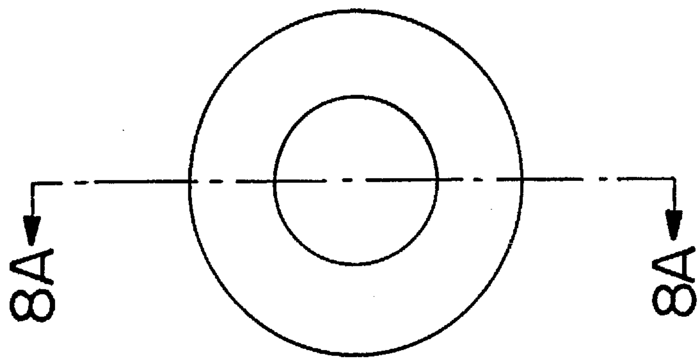

FIG.8B

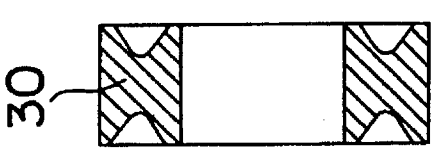

FIG.8A

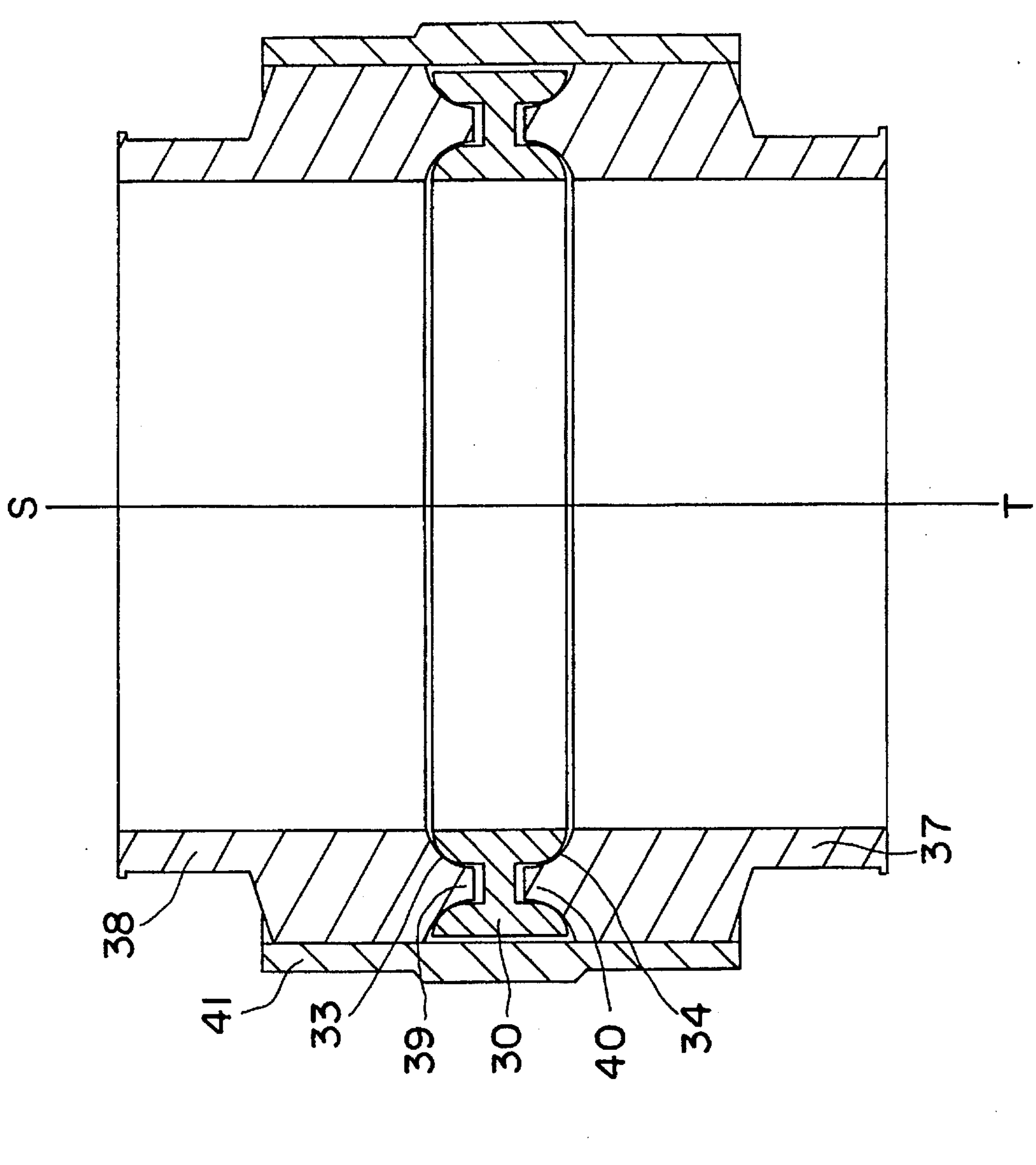

FIG. 9

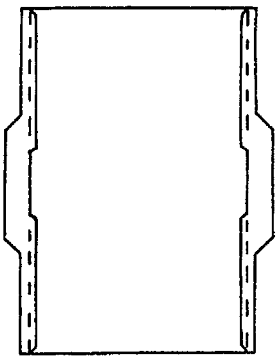

FIG. 11A

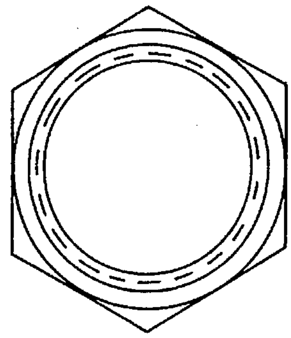

FIG. 11B

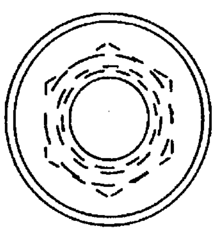

FIG. 10B

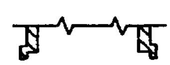

FIG. 10D

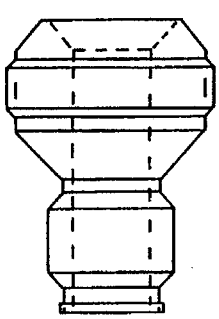

FIG. 10A

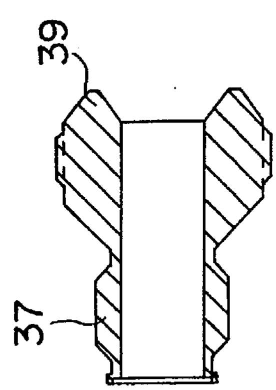

FIG. 10C

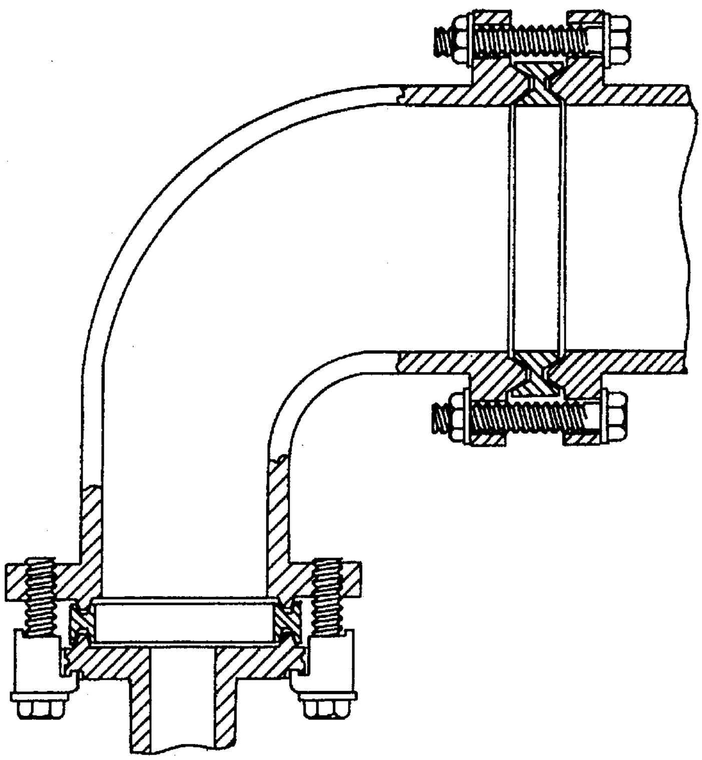

FIG. 12B

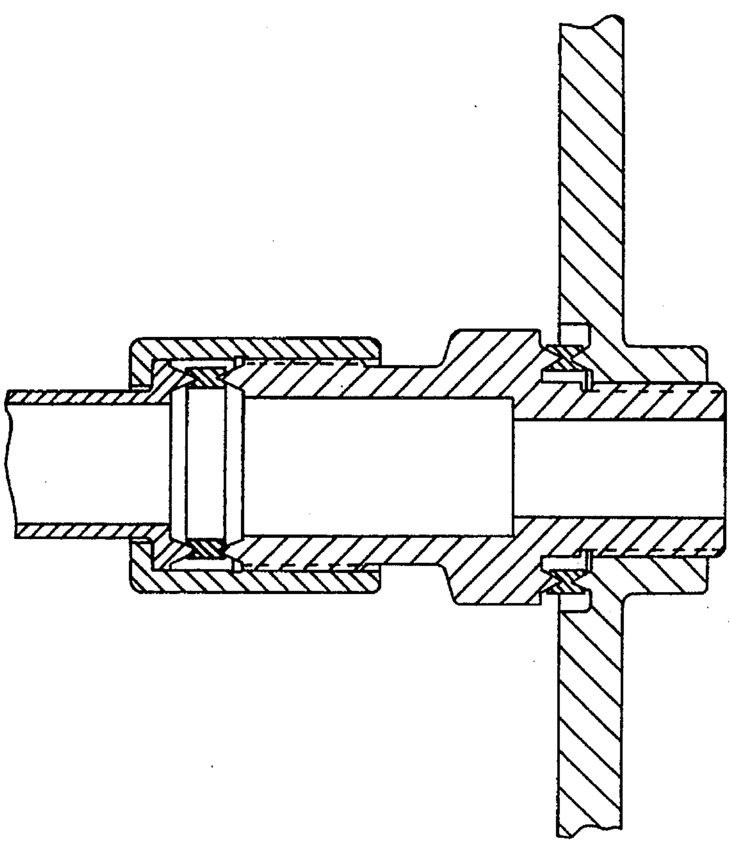

FIG. 12A

CONTRACTING/EXPANDING SELF-SEALING CRYOGENIC TUBE SEALS

The subject invention was made with government support under a research project supported by NASA-Kennedy Space Center and under Contract No. NAS10-11569 and Research Grant No. NAG10-0083. The government has certain rights in this invention.

This is a division of application Ser. No. 08/071,418, filed Jun. 1, 1993.

BACKGROUND OF THE INVENTION

The rigorous conditions of very low operating temperatures coupled with high pressure impose extreme difficulties for controlling cryogen leakage from in-line tube fittings. The KC126 fitting, which has been used by NASA in the fuel lines of the space shuttle, has been found to leak. We have shown that the KC126 fitting leaks at 205K, and at 77K has a leak mass flux of 1.28×10^{-3} kg/min. See also Moore, Z., D. Capellin, A. Rodriguez, J. England (1988) "LH_2 TSM Leakage Problem," Interim Report: DM-MED-4, NASA, J. F. X. Space Center. Accordingly, there exists a need for an improved design of cryogenic seal for tube fittings such as those used in the space shuttle, and which is reusable and seals under extremes of low temperature and high pressure. Such a seal would have wide application in the cryogenic art.

The problem of sealing a joint between taro interconnecting pieces that are designed to operate at cryogenic temperatures has been previously recognized. In pan, this problem was addressed in U.S. Pat. No. 3,630,533, issued Dec. 28, 1971 to Butler et al., entitled "Dynamic Seal for Cryogenic Fluids." An additional problem addressed by Butler et al. is the high temperature sealing problem, which influenced Butler et al.'s design. Butler et al. used a circular sealing ring made from a fluorocarbon plastic material to seal two metal tubular couplings. The sealing ring is pressed onto a radially outward surface of one of the metal couplings. The sealing ring has a radially inward protruding annular rib which elastically and inelastically deforms as the sealing ring is pressed into place. This arrangement effects a sealing engagement between the sealing ring and the metal coupling at temperatures reported to be within the range of 70° F. to −423° F. At normal temperatures, the inner surface of the sealing ring is held in sealing engagement by the elastic preload induced by the initial interference press-fit and deformation of the protruding annular rib. In addition to the preload, a circumferential tension is generated in the sealing ring as the temperature decreases, because the sealing ring's coefficient of thermal expansion and contraction is greater than the coefficient of thermal expansion and contraction of the metal couplings. Thus, because of the differences in the expansion coefficients of the sealing ring and the metal coupling that it is pressed onto, the sealing engagement between these members of two different materials becomes tighter as the temperature decreases. However, in Butler et al.'s design, each time two metal tubular couplings are sealed together, the complex plastic sealing ting must be inelastically deformed into a particular configuration. Since the sealing ting is irreparably deformed by its installation, after separation of the two couplings for maintenance or other reasons, it is necessary to replace the sealing ting before the two couplings can be rejoined. Such a "use once and throw away" approach is wasteful, ultimately expensive, and troublesome if a replacement ring is not readily available. A coupling between two members which can be joined

and separated, without requiring a new sealing ring each time, is needed.

BRIEF SUMMARY OF THE INVENTION

The subject invention, contracting/expanding self-sealing cryogenic tube seals, are thermal-contraction controlled-action sealing and gripping devices which utilize the differences of the thermal contraction of selected dissimilar materials in a specially designed and composed structure to self-tighten the seal via sloped-surface sealing between coupled members as the temperature decreases from ambient temperature. "Sloped-surface sealing" means that the contact points creating the seal are not the result of contact of parallel surfaces. In one preferred embodiment, the cooling process causes the contraction of a sealing spacer, further gripping the member ends, and causes the contraction of a housing nut, further forcing the coupling member ends together, thereby taking advantage of sloped-surface sealing in a novel way and preventing leakage of the flowing cryogen.

The contracting/expanding serf-sealing cryogenic tube seals are leak-free from room temperature to cryogenic temperatures as low as that of liquid helium and, unlike anything known in the an, provide easily remountable tube connections for high pressure and low temperature applications.

The contracting/expanding self-sealing cryogenic tube seal is a general purpose cryogenic tube seal. It provides reliable leak-free connections for the low/high pressure and low temperature working conditions in cryogenic applications. It can be easily applied to various cryogenic fittings and valves. Some basic advantages of contracting serf-sealing cryogenic fittings are summarized as follows:

1. Applicable to any low temperatures and temperature cycling.
2. Works on most common magnetic/non-magnetic tube materials.
3. Seals on machined surfaces.
4. Does not reduce the flow area.
5. Works on vacuum as well as low or high pressures.
6. Simple in structure for production and handling.
7. Easy to use, similar to the standard SAE fittings.
8. Easy to assemble and disassemble.
9. Ability to reuse without special maintenance or replacement.
10. Not sensitive to the applied coupling torques.
11. Not sensitive to the moment from other components.
12. Not corrosive for common cryogen.
13. Applicable to most cryogenic tube connections.

Design criteria for contracting/expanding self-sealing cryogenic (CESSC) tube seals are taught which must be applied in accord with the subject invention, and which depend on the properties of selected materials as well as the configuration of the seal. These criteria, illustrated by the following examples, enable the construction by means well known in the art of a tremendous number of varying embodiments, all of which are based on the novel sloped-sealing concepts taught herein, as will be readily apparent to the skilled artisan.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** depicts a longitudinal section through a preferred embodiment of a contracting self-sealing cryogenic tube seal.

FIG. **2** depicts a longitudinal section through a variation of the embodiment depicted in FIG. **1**, wherein the O-ring spacer has been replaced with a modified spacer.

FIG. **3** depicts a longitudinal section through an alternative embodiment of a contracting self-sealing cryogenic tube seal having only three components.

FIG. **4** depicts a longitudinal section through an alternative embodiment of the contracting self-sealing cryogenic tube seal.

FIG. **5** depicts the geometric analysis of cryogenic shrinkage of the components of the contracting self-sealing cryogenic tube seal.

FIG. **6** is a graphic representation of the design criteria for the contracting self-sealing cryogenic tube seal.

FIG. **7** depicts a longitudinal section through a preferred embodiment of a contracting/expanding self-sealing cryogenic tube seal.

FIG. **8** is a schematic drawing of an H-shaped spacer of a preferred embodiment of the contracting/expanding self-sealing cryogenic tube seal.

FIG. **9** depicts an H-shaped spacer of the contracting/expanding self-sealing cryogenic tube seal wherein the sloped surface sealing is accomplished via contact of curved surfaces.

FIG. **10** is a schematic drawing of a preferred embodiment of a coupling member of the contracting/expanding self sealing cryogenic tube seal.

FIG. **11** is a schematic drawing of a preferred embodiment of the housing nut of the contracting/expanding self sealing cryogenic tube seal.

FIG. **12** depicts various embodiments of the contracting/expanding self sealing cryogenic tube seal in potential operational configurations.

DETAILED DISCLOSURE OF THE INVENTION

Following are examples which illustrate procedures, including the best mode, for practicing the invention. These examples should not be construed as limiting.

Example 1—A Preferred Embodiment

In a preferred embodiment, as depicted in FIG. **1**, the contracting self-sealing cryogenic tube seal consists of four basic components: metal coupling members **1** and **2**, each having a male an-flare tube end **14** and **15**, respectively, an O-ring spacer **3**, and a housing nut **4**. Housing nut **4** comprises internal threads **13** for threaded engagement with external threads **5** and **6** on coupling members **1** and **2**, respectively. The O-ring spacer **3** rests between two male an-flare coupling members **1** and **2**.

Various pans of contracting serf-sealing cryogenic tube seals are made of dissimilar solid bar metals, thereby taking advantage of their different coefficients of thermal contraction. The materials for O-ring spacer **3** and housing nut **4** have higher values of the coefficient of thermal contraction than does the material used for coupling members **1** and **2**. In the preferred embodiment, the components are axisymmetric (symmetric about an axis).

Assembly of the contracting self-sealing cryogenic tube seal depicted in FIG. **1** is a simple matter of engaging housing nut **4** with coupling member **1** until the an-flare tube end **14** of coupling member **1** is positioned approximately in the middle of housing nut **4**, proximal to the lateral plane represented by segment FG. O-ring spacer **3** is then inserted into homing nut **4** until it contacts an-flare tube end **14** of coupling member **1**. Coupling member **2** is then engaged into housing nut **4** until an-flare tube end **15** is secured against O-ring spacer **3**. The sloped surface of the an-flare tube ends allows for contraction of the spacer while ensuring that a tight seal is maintained.

In operation, cryogenic fluid begins to flow through the contracting self-sealing cryogenic tube fitting along longitudinal axis ST as depicted in FIG. **1**. For ease of discussion, movement toward position S will be referred to as "upward" and movement toward position T will be referred to as "downward;" movement toward axis ST will be referred to as "inward" and movement away from axis ST will be referred to as "outward." As the cryogenic fluid flows, the temperature of all pans of the contracting self-sealing cryogenic tube seal begins to decrease. Accordingly, the various pans of the tube seal shrink in size. Contact portion **10** at tube end **14** tends to shrink upward and inward. Contact portion **11** at O-ring spacer **3** tends to shrink downward and inward. That portion **18** of housing nut **4**, which is depicted above lateral plane FG, tends to shrink downward and inward, while housing nut portion **19**, below plane FG, tends to shrink upward and inward. Because O-ring spacer **3** and housing nut **4** are made of materials having a larger coefficient of thermal contraction than are coupling members **1** and **2** (and thus tube ends **14** and **15**), the inward shrinkage of O-ring spacer **3** tends to cause it to press even more tightly against tube ends **14** and **15**. Similarly, shrinkage of housing nut **4** tends to force tube ends **14** and **15** toward each other, as well as providing a tighter engagement of threaded portions **13**, **5**, and **6**. Thus, the effects of thermal contraction will always maintain a leak-free seal in the contracting self-sealing cryogenic seal.

Example 2—Some Alternative Embodiments

FIGS. **2**, **3**, and **4** depict exemplary alternative embodiments of the subject invention. To ensure proper sealing, contact surfaces of the components are axisymmetric. FIG. **2** depicts an embodiment similar to that depicted in FIG. **1** except that O-ring spacer **3** has been replaced with a flared spacer **27** having opposed female-flared contact surfaces **28** and **29**, each having a complementary shape to tube ends **14** and **15**, respectively, such that a tight seal is maintained therebetween in accord with the design criteria described hereinafter.

FIG. **3** depicts coupling member **1** with male an-flare tube end **14**, coupling member **21** with female flare tube end **22**, and housing nut **20**, having a large bore at one end with internal threaded means for receiving and engaging coupling member **1** and a smaller (step down) bore at the other end, which is just large enough to surround coupling member **21**, but not large enough to allow female flare tube end **22** to pass through. The internal surface of the step-down end of housing nut **20** defines a circumferential flange **23**, radially sloping downward and outward. Housing nut **20** engages coupling member **1**, and as housing nut **20** is tightened about coupling member **1**, flange **23** engages a circumferential lip **24** on coupling member **21**, lip **24** having a complementary slope to that of flange **23** such that contact is maintained between lip **24** and flange **23**, and pulls coupling member **21**

such that the female flare tube end **22** of coupling member **21** is thereby brought into contact with male an-flare tube end **14** of coupling member **1**, similar to the method by which a garden house is brought into contact with a spigot. Secured contact between tube end **14** and tube end **22** is thereby maintained in accord with the disclosed design criteria. To maintain the sloped-surface seal of this embodiment leak-free at cryogenic temperatures, coupling member **21** and housing nut **20** are made of materials having a larger coefficient of thermal expansion than the material of coupling member **1**, all in accord with the design criteria. For example, coupling member **21** and housing nut **20** may be made of copper, if coupling member **1** is stainless steel.

The embodiment depicted in FIG. **4** combines features of the embodiments depicted in FIGS. **1** and **3**. Housing nut **4** is engaged with coupling member **1** until the an-flare tube end **14** of coupling member **1** is positioned approximately in the middle of housing nut **4**. Housing nut **4** then engages collar **25**, which has external threaded means for being engaged and secured by the internal threaded means of housing nut **4**, and which also has a wedge end **26** which engages lip **24** on coupling member **21** and forces female flare tube end **22** into secured contact with male an-flare tube end **14**. Thus, it can be seen that the collar and wedge component of this embodiment can be used with housing nut **4** to effectively replace the flange **23** and small bore end of housing nut **20** of the embodiment depicted in FIG. **3**. To maintain the sloped-surface seal of this embodiment leak-free at cryogenic temperatures, collar **25** (having wedge end **26**), as well as coupling member **1**, are made of materials having a smaller coefficient of thermal expression than the material of housing nut **4** and coupling member **21** (having lip **24**).

Example 3—Design. Criteria of Contracting/Expanding Self-Sealing Cryogenic Seals

According to the theory of Gas Dynamics and the linear analysis of thermal contraction, some criteria for the design of contracting/expanding self-sealing cryogenic seals are given below:

(1) Design criteria for two components—tube and spacer:

$$\alpha < \cos^{-1}\left\{\left[\gamma_o + \left(\frac{\gamma_o - 1}{2\beta}\right)^2\right]^{\frac{1}{2}} - \frac{\gamma_o - 1}{2\beta}\right\}$$

$$\beta < \frac{\gamma_o - 1}{\frac{\gamma_o}{\cos(\alpha)} - \cos(\alpha)}, \quad \gamma_o > \frac{1 - \beta\cos(\alpha)}{1 - \frac{\beta}{\cos(\alpha)}}$$

(2) Design criteria for three components—housing nut, tube-end, and spacer:

$$\gamma_o(T) > \frac{C_1(T)}{C_2}$$

where

$$C_1(T) = \sin\left[\alpha + \tan^{-1}\left(\frac{1 - \beta\cos\alpha}{\frac{\lambda}{\tan\alpha}(1 - \gamma_h(T)) - \gamma_h(T)\beta\sin\alpha}\right)\right] \cdot \left[(1 - \beta\cos\alpha)^2 + \left(\frac{\lambda}{\tan\alpha}(1 - \gamma_h(T)) - \gamma_h(T)\beta\sin\alpha\right)^2\right]^{1/2}$$

$$C_2 = (\cos\alpha - \beta)$$

Referring to FIG. **5**, a is the an-flared angle of the tube ends. fi is the radius ratio of O-ring spacer r_1/R. λ is the ratio of the thickness of tube-end to the radius of the spacer, $\gamma_0(\gamma_o=\epsilon_o/\epsilon_p)$ is the ratio of thermal contraction of the material used for the spacer to that of the tube ends $\gamma_5(\gamma_h=\epsilon_h/\epsilon_p)$ is the ratio of thermal contraction of the material used for the housing-nut to that of the tube ends. The parameters, α, β, and λ, are the parameters of the seal geometry. γ_o and γ_h are the functions of temperature, which can be found from the tables of material properties and are well known in the art.

These criteria have been illustrated in the graphs of FIG. **6**. The physics of the thermal contracting process or the thermal and geometric effects of the contracting/expanding self-sealing cryogenic seal is revealed by these criteria. The contracting/expanding self-sealing cryogenic seal is predictable in its response to temperature fluctuations-it consistently fulfills the promise of self-sealing for cryogenic applications.

A linear approximation of the sealing process in a thermal-contraction controlled-action seal by a simple geometric analysis was used to calculate design parameters of the contracting/expanding self-sealing cryogenic seal. The contracting serf-sealing cryogenic tube seals exemplified herein were designed in accord with this analysis and have successfully passed a series of tests in the cryogenic leak test system with a temperature drop from room temperature down to the liquid helium temperature in the Cryogenic Laboratory of Florida Atlantic University.

Shown in FIG. **5** is the cross-section of an O-ring spacer seated between an-flared tube ends with axial angle, α, before and after cooling period. Both O-ring spacer and tube end, which have different coefficients of thermal expansion, shrink axisymmetrically in the cooling process. A_1 and A_2 are two contact points of the mating pans before and after cooling. Because of the thermal contraction, the original contact point, A_1, in the tube end moves to D, with a radial shrinkage, $\Delta t=A_1E$, and an axial shrinkage, $\Delta L=ED$.

A maximum value of the shrinkage of the tube end in axial direction, ΔL, can be obtained if presuming a zero-thermal-stress condition, which means free contracting of both O-ring spacer and tube end without losing contact with each other. It is apparent that if the actual axial shrinkage of the tube end is larger than the zero-thermal-stress shrinkage, ΔL, the contracting self-sealing cryogenic seal will never achieve a leak-free seal.

From the geometry in FIG. **5**, if we let $\Delta L'=A_1B$ and $\Delta t'=A_1C$, then

$$\frac{\Delta L}{\Delta L'} = \frac{\Delta t' - \Delta t}{\Delta t'}$$

and $\Delta t'=\Delta L'\tan\alpha$, we have

$$\Delta L = \Delta L' - \frac{\Delta t}{\tan\alpha} \tag{1}$$

and also

$$\Delta L'\sin\alpha + r_1 = \Delta R\cos\alpha + r_2$$

we have,

$$\Delta L' = \frac{\Delta R}{\tan\alpha} - \frac{\Delta r}{\sin\alpha} \tag{2}$$

where $\Delta r = r_1 - r_2$. Combining Eq. (1) and (2),

$$\Delta L = \frac{1}{\tan\alpha}\left(\Delta R - \Delta t - \frac{\Delta r}{\cos\alpha}\right) \tag{3}$$

Assuming a linear contraction as a first approximation, i.e., $\Delta R = \epsilon_o R$, since r is much smaller than R, and $\Delta r = \epsilon_o r_1$ and $\Delta t = \epsilon_p (R - r_1 \cos\alpha)$ for the same approximation, where e_o and e_p are the coefficients of thermal expansion of O-ring spacer and tube end, respectively. Substituting ΔR, Δt, and Δr into Eq. (3), we have,

$$\Delta L = \frac{1}{\tan\alpha}\left[R(\epsilon_o - \epsilon_p) - r_1\left(\frac{\epsilon_o}{\cos\alpha} - \epsilon_p\cos\alpha\right)\right] \tag{4}$$

Let $\gamma = \epsilon_o/\epsilon_p$, and $\beta = r_1/R$, we can rewrite Eq. (4) as

$$\Delta L = \frac{R\epsilon_p}{\tan\alpha}\left[\gamma\left(1 - \frac{\beta}{\cos\alpha}\right) + \beta\cos\alpha - 1\right] \tag{5}$$

The maximum axial shrinkage of tube end, ΔL, from the above equation, is a function of three parameters, α, β, and γ, where α is the an-flared angle of the tube end, β is the radius ratio of the O-ring spacer, and γ is the ratio of thermal properties of material used for two mating parts.

In order to have a positive value of ΔL, the term in brackets must be positive, which leads to three design criteria for three parameters, each one depending on the other two, which are given as follows:

$$\gamma > \frac{1 - \beta\cos\alpha}{1 - \frac{\beta}{\cos\alpha}} \tag{A}$$

$$\beta < \frac{\gamma - 1}{\frac{\gamma}{\cos\alpha} - \cos\alpha} \tag{B}$$

$$\alpha < \cos^{-1}\left\{\left[\gamma + \left(\frac{\gamma - 1}{2\beta}\right)^2\right]^{\frac{1}{2}} - \frac{\gamma - 1}{2\beta}\right\} \tag{C}$$

According to the above criteria, α and β do not have lower limitations except for the negative values, which are meaningless for an O-ring seal. The lower limitations actually depend on the strength of the materials. The minimum value of a depends on the requirement for the wall thickness of the tube end. The minimum value of fi depends on the requirement for the radius of the cross section of the O-ring spacer. The graphs of FIG. **6** represent possible values for α, β, and γ that can be used for the design of contracting self-sealing cryogenic seal. In Table 1 a dimensionless parameter of $\Delta L/R\epsilon_p$ is given which is computed from Eq. (5) for the convenience of applications. For example, if we choose $\alpha = 35°$, and $\beta = 0.3$, then γ must be larger than 1.2. If we chose $\gamma = 6$ (for copper O-ring and invar tube end), we have $\Delta L/R\epsilon_p = 4.5$. If R=8 mm, and $\epsilon_{op} = 0.06\%$ (invar at 6K), the maximum promising axial shrinkage, ΔL=0.022 mm. This is an approximate value for the tested contracting self-sealing cryogenic seal at liquid helium temperature.

Example 4—Selection of Materials for Contracting/Expanding Self-Sealing Cryogenic Seals

The function of a contracting/expanding self-sealing cryogenic seal relies upon the differences of the thermal contractions of dissimilar materials in a specially composed structure which, in a novel, advantageous manner uses the Concept of sloped-surface sealing. The selection of materials is basically determined by the nature of thermal contraction of the materials used for each of the components. The contracting/expanding self-sealing cryogenic seal works only if it is designed to meet the criteria which are dependent upon not only the thermal properties of materials, but also the geometric parameters. The selection of the materials, therefore, is not an independent factor in order to achieve a self-sealing purpose. It must be considered together with the geometric parameters of the components of the seal. In this regard, the contracting self-sealing cryogenic seal is an integrated unit.

One of the possible combinations is given as follows: The material for tube ends is commonly the same as that for the tubing bodies. For cryogenic situations, stainless steel is a commonly-used material for tubing bodies. Therefore, among other common engineering materials, in the embodiment depicted in FIG. **1**, copper is one of the possible choices for the housing nut and the O-ring spacer, used with the stainless steel tube ends. However, the geometric configuration must meet the contracting serf-sealing cryogenic criteria disclosed above with the given parameter of thermal contraction ratio calculated for copper to stainless steel.

Example 5—Test Results of Various Embodiments of Contracting Self-Sealing Cryogenic Seal

The contracting self-sealing cryogenic seals have passed a series of tests in the cryogenic leak test system at Florida Atlantic University. The detailed information of the cryogenic leak test system is given in Jia, L. X., D. Moslemian, W. L. Chow (1992) "Cryogenic leak testing of tube fittings/valves," Cryogenics 32(9):833–839, which is incorporated herein by reference thereto. The tests were conducted under two different temperature levels, LN_2 temperature (≈77K), and LHe temperature (≈4K).

For the leak test under LN_2 temperature, the highest internal pressure against the external vacuum applied to this seal has been 31×10^5 Pa, nearly two times the working pressure in the space shuttle. The test lasted about ten hours without showing any signs of leak from vacuum gauges at pressure of 5×10^{-4} Bar within the sample chamber. In another test, initial pressurization was to 27.1×10^5 Pa. As the temperature dropped to 140K, additional gaseous helium was supplied to increase the internal pressure from 12×10^5 Pa to 26.2×10^5 Pa. When the equilibrium temperature of 77K was reached, internal pressure was reduced down to 17.2×10^5 Pa and kept under this condition for another 10 hours. Throughout the testing period, no pressure increase was detected in the evacuated sample chamber used to house the seal.

For the leak test under LHe temperature, a constant internal pressure of 27.1×10^5 Pa against the external vacuum was applied to the contracting self-sealing cryogenic tube seal. The test lasted 5 hours at the temperature of 4.5K~6.9K without showing any signs of leak from vacuum gauges at pressure of 1×10^{-6} Bar within the sample chamber. The tests on the contracting self-sealing cryogenic tube seals at LHe temperature indicated that it is feasible to develop a new series of cryogenic tube seals for the LH_2 transfer lines of the space shuttle, as well as for other cryogenic applications, based on the novel sloped-sealing technology taught herein.

Example 6—Contracting/Expanding Self-Sealing Cryogenic Seal

The concept for a contracting self-sealing cryogenic tube seal can be extended for a special application where a wide range and high rate of temperature cycling is a significant feature of the working condition. A contracting/expanding self-sealing cryogenic tube fitting is schematically shown in

FIG. 7. With larger thermal contraction and thermal expansion coefficients, the shrinking or expanding displacement of the spacer caused by temperature cycling always tends to prevent the appearance of any possible leak gap between the tube ends and the spacer, no matter whether the working temperature is decreasing or increasing. A similar analysis for a contracting/expanding self-sealing cryogenic seal can be easily obtained as described above by considering an additional reverse thermal process of temperature increase.

In a contracting/expanding self-sealing cryogenic seal as depicted in FIG. 7, the spacer **30** has an H-shaped cross-section, having opposed V-shaped female sloped-sealing surfaces **31** and **32** at each end which contact the complementary sloped male an-flare tube ends **39** and **40**, respectively, of the coupling members **37** and **38**. The male angle of the tube end is made slightly larger than the female angle of the corresponding surface of the spacer **30**. A similar H-shaped spacer/seal is depicted in FIG. **9**, wherein the sloped surface sealing is accomplished by contact of curved surfaces. When temperature is decreased, the outwardmost contact surfaces **33** and **34** of the spacer **30** will tightly grip the tube ends **39** and **40**. When temperature is increased, the inside contact surfaces **35** and **36** of the spacer **30** will tightly press against the tube ends **39** and **40**. Therefore, a fight seal is achieved under the temperature cycling condition. Since the temperature changes in two opposite directions, the thermal behavior of the housing nut **41** no longer contributes consistently for tube sealing during the temperature cycling. Therefore, in a preferred embodiment, the material for the housing nut **41** has a smaller coefficient of thermal contraction (or expansion) than does the spacer **30**. The material for coupling members **37** and **38** also has a smaller coefficient of thermal expansion than does that of spacer **30**. The selection of materials for the spacer **30** and tube ends **39** and **40** of contracting/expanding self-sealing cryogenic seals follows the same design criteria given above. In a preferred embodiment, the subject seal, seemingly sophisticated, surprisingly simply solves sometimes severe system seepage substantially superior to standard space shuttle seals by specially-selected, securely sandwiched, sloped-surface spacers snugly surrounding stainless steel surfaces shown self-sealing by sequential shrinking and swelling.

One preferred embodiment of the contracting/expanding self-sealing cryogenic seal was fabricated for use in the LH_2 lines of the space shuttle at the JFK Space Center. The H-shaped spacer **30** (see FIGS. **7** and **8**) has a larger thermal expansion coefficient than that of the tube ends **39** and **40** between which it is sandwiched. Shrinkage or expansion of this spacer always tends to prevent the formation of any possible leaking gap between the tube ends and the spacer, regardless of whether the working temperature is decreasing or increasing. The contracting/expanding serf-sealing cryogenic tube seal provides leak-free and easily remountable tube connections from temperatures as high as the component materials can withstand to cryogenic temperatures as low as that of liquid helium, and under pressures varying from vacuum to several hundred psi or more. The seal is especially effective in applications where a wide range and high rate temperature cycling are significant features of the working conditions. The seal can be easily integrated into all kinds of cryogenic tubing components, such as fittings and valves. Several possible configurations which employ the contracting/expanding self-sealing cryogenic tube seal are shown in FIG. **12**. The contracting/expanding serf-sealing cryogenic seal has passed the temperature cycling test: first cooled down from 296K to 12K, then heated up to 300K within 20 minutes, and then cooled down again to 77K, while the pressure maintained 400 psig, without showing any sign of leak.

It should be understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application and the scope of the appended claims.

TABLE 1

Design Parameters for CSSC Tube Fitting, ($d1=\Delta L/R\epsilon_p$).

gama(beta=	0.1000000	alfa=	5) >	1.000848
	gama	beta	alfa	
d1(	1.000848	0.1000000	5)=	0.0000000E+00
d1(	1.500848	0.1000000	5)=	5.141342
d1(	2.000848	0.1000000	5)=	10.28268
d1(	2.500848	0.1000000	5)=	15.42402
d1(	3.000848	0.1000000	5)=	20.56536
d1(	3.500848	0.1000000	5)=	25.70670
d1(	4.000848	0.1000000	5)=	30.84805
d1(	4.500848	0.1000000	5)=	35.98938
d1(	5.000848	0.1000000	5)=	41.13073
d1(	5.500848	0.1000000	5)=	46.27207
d1(	6.000848	0.1000000	5)=	51.41341
gama(beta=	0.1000000	alfa=	10) >	1.003408
	gama	beta	alfa	
d1(	1.003408	0.1000000	10)=	0.0000000E+00
d1(	1.503408	0.1000000	10)=	2.547703
d1(	2.003408	0.1000000	10)=	5.095405
d1(	2.503408	0.1000000	10)=	7.643107
d1(	3.003408	0.1000000	10)=	10.19081
d1(	3.503408	0.1000000	10)=	12.73851
d1(	4.003408	0.1000000	10)=	15.28621
d1(	4.503408	0.1000000	10)=	17.83392
d1(	5.003408	0.1000000	10)=	20.38162
d1(	5.503408	0.1000000	10)=	22.92932
d1(	6.003408	0.1000000	10)=	25.47702
gama(beta=	0.1000000	alfa=	15) >	1.007736
	gama	beta	alfa	
d1(	1.007736	0.1000000	15)=	0.0000000E+00
d1(	1.507736	0.1000000	15)=	1.672840
d1(	2.007736	0.1000000	15)=	3.345681
d1(	2.507736	0.1000000	15)=	5.018521
d1(	3.007736	0.1000000	15)=	6.691361
d1(	3.507736	0.1000000	15)=	8.364202
d1(	4.007736	0.1000000	15)=	10.03704
d1(	4.507736	0.1000000	15)=	11.70988
d1(	5.007736	0.1000000	15)=	13.38272
d1(	5.507736	0.1000000	15)=	15.05556
d1(	6.007736	0.1000000	15)=	16.72840
gama(beta=	0.1000000	alfa=	20) >	1.013931
	gama	beta	alfa	
d1(	1.013931	0.1000000	20)=	0.0000000E+00
d1(	1.513931	0.1000000	20)=	1.227548
d1(	2.013931	0.1000000	20)=	2.455097
d1(	2.513931	0.1000000	20)=	3.682646
d1(	3.013931	0.1000000	20)=	4.910194
d1(	3.513931	0.1000000	20)=	6.137743
d1(	4.013931	0.1000000	20)=	7.365292
d1(	4.513931	0.1000000	20)=	8.592841
d1(	5.013931	0.1000000	20)=	9.820390
d1(	5.513931	0.1000000	20)=	11.04794
d1(	6.013931	0.1000000	20)=	12.27549
gama(beta=	0.1000000	alfa=	25) >	1.022151
	gama	beta	alfa	
d1(	1.022151	0.1000000	25)=	0.0000000E+00
d1(	1.522151	0.1000000	25)=	0.9539434
d1(	2.022151	0.1000000	25)=	1.907887
d1(	2.522151	0.1000000	25)=	2.861830
d1(	3.022151	0.1000000	25)=	3.815774
d1(	3.522151	0.1000000	25)=	4.769717
d1(	4.022151	0.1000000	25)=	5.723660
d1(	4.522151	0.1000000	25)=	6.677603
d1(	5.022151	0.1000000	25)=	7.631547

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ($d1=\Delta L/R\epsilon_p$).

d1(	5.522151	0.1000000	25	)=	8.585490
d1(	6.022151	0.1000000	25	)=	9.539434
gama(beta=	0.1000000	alfa=	30) >		1.032636
	gama	beta	alfa		
d1(	1.032636	0.1000000	30	)=	0.0000000E+00
d1(	1.532636	0.1000000	30	)=	0.7660255
d1(	2.032636	0.1000000	30	)=	1.532051
d1(	2.532636	0.1000000	30	)=	2.298077
d1(	3.032636	0.1000000	30	)=	3.064102
d1(	3.532636	0.1000000	30	)=	3.830127
d1(	4.032636	0.1000000	30	)=	4.596153
d1(	4.532636	0.1000000	30	)=	5.362179
d1(	5.032636	0.1000000	30	)=	6.128204
d1(	5.532636	0.1000000	30	)=	6.894230
d1(	6.032636	0.1000000	30	)=	7.660254
gama(beta=	0.1000000	alfa=	35) >		1.045747
	gama	beta	alfa		
d1(	1.045747	0.1000000	35	)=	0.0000000E+00
d1(	1.545747	0.1000000	35	)=	0.6269017
d1(	2.045747	0.1000000	35	)=	1.253803
d1(	2.545747	0.1000000	35	)=	1.880705
d1(	3.045747	0.1000000	35	)=	2.507607
d1(	3.545747	0.1000000	35	)=	3.134508
d1(	4.045747	0.1000000	35	)=	3.761410
d1(	4.545747	0.1000000	35	)=	4.388311
d1(	5.045747	0.1000000	35	)=	5.015213
d1(	5.545747	0.1000000	35	)=	5.642115
d1(	6.045747	0.1000000	35	)=	6.269017
gama(beta=	0.1000000	alfa=	40) >		1.062034
	gama	beta	alfa		
d1(	1.062034	0.1000000	40	)=	−7.1034052E−08
d1(	1.562034	0.1000000	40	)=	0.5180907
d1(	2.062034	0.1000000	40	)=	1.036181
d1(	2.562034	0.1000000	40	)=	1.554272
d1(	3.062034	0.1000000	40	)=	2.072362
d1(	3.562034	0.1000000	40	)=	2.590453
d1(	4.062034	0.1000000	40	)=	3.108544
d1(	4.562034	0.1000000	40	)=	3.626635
d1(	5.062034	0.1000000	40	)=	4.144725
d1(	5.562034	0.1000000	40	)=	4.662816
d1(	6.062034	0.1000000	40	)=	5.180906
gama(beta=	0.1000000	alfa=	45) >		1.082358
	gama	beta	alfa		
d1(	1.082358	0.1000000	45	)=	0.0000000E+00
d1(	1.582358	0.1000000	45	)=	0.4292893
d1(	2.082358	0.1000000	45	)=	0.8585786
d1(	2.582358	0.1000000	45	)=	1.287868
d1(	3.082358	0.1000000	45	)=	1.717157
d1(	3.582358	0.1000000	45	)=	2.146446
d1(	4.082358	0.1000000	45	)=	2.575736
d1(	4.582358	0.1000000	45	)=	3.005025
d1(	5.082358	0.1000000	45	)=	3.434314
d1(	5.582358	0.1000000	45	)=	3.863604
d1(	6.082358	0.1000000	45	)=	4.292893
gama(beta=	0.1000000	alfa=	50) >		1.108113
	gama	beta	alfa		
d1(	1.108113	0.1000000	50	)=	0.0000000E+00
d1(	1.608113	0.1000000	50	)=	0.3542794
d1(	2.108113	0.1000000	50	)=	0.7085589
d1(	2.608113	0.1000000	50	)=	1.062838
d1(	3.108113	0.1000000	50	)=	1.417118
d1(	3.608113	0.1000000	50	)=	1.771397
d1(	4.108113	0.1000000	50	)=	2.125677
d1(	4.608113	0.1000000	50	)=	2.479956
d1(	5.108113	0.1000000	50	)=	2.834235
d1(	5.608113	0.1000000	50	)=	3.188515
d1(	6.108113	0.1000000	50	)=	3.542794
gama(beta=	0.1000000	alfa=	55) >		1.141690
	gama	beta	alfa		
d1(	1.141690	0.1000000	55	)=	0.0000000E+00
d1(	1.641690	0.1000000	55	)=	0.2890651

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ($d1=\Delta L/R\epsilon_p$).

d1(	2.141690	0.1000000	55	)=	0.5781302
d1(	2.641690	0.1000000	55	)=	0.8671951
d1(	3.141690	0.1000000	55	)=	1.156260
d1(	3.641690	0.1000000	55	)=	1.445325
d1(	4.141690	0.1000000	55	)=	1.734390
d1(	4.641690	0.1000000	55	)=	2.023455
d1(	5.141690	0.1000000	55	)=	2.312521
d1(	5.641690	0.1000000	55	)=	2.601585
d1(	6.141690	0.1000000	55	)=	2.890651
gama(beta=	0.1000000	alfa=	60) >		1.187500
	gama	beta	alfa		
d1(	1.187500	0.1000000	60	)=	0.0000000E+00
d1(	1.687500	0.1000000	60	)=	0.2309401
d1(	2.187500	0.1000000	60	)=	0.4618802
d1(	2.687500	0.1000000	60	)=	0.6928203
d1(	3.187500	0.1000000	60	)=	0.9237604
d1(	3.687500	0.1000000	60	)=	1.154701
d1(	4.187500	0.1000000	60	)=	1.385641
d1(	4.687500	0.1000000	60	)=	1.616581
d1(	5.187500	0.1000000	60	)=	1.847521
d1(	5.687500	0.1000000	60	)=	2.078461
d1(	6.187500	0.1000000	60	)=	2.309401
gama(beta=	0.1000000	alfa=	65) >		1.254602
	gama	beta	alfa		
d1(	1.254602	0.1000000	65	)=	0.0000000E+00
d1(	1.754602	0.1000000	65	)=	0.1779849
d1(	2.254602	0.1000000	65	)=	0.3559698
d1(	2.754602	0.1000000	65	)=	0.5339549
d1(	3.254602	0.1000000	65	)=	0.7119397
d1(	3.754602	0.1000000	65	)=	0.8899247
d1(	4.254602	0.1000000	65	)=	1.067910
d1(	4.754602	0.1000000	65	)=	1.245895
d1(	5.254602	0.1000000	65	)=	1.423879
d1(	5.754602	0.1000000	65	)=	1.601864
d1(	6.254602	0.1000000	65	)=	1.779849
gama(beta=	0.1000000	alfa=	70) >		1.364855
	gama	beta	alfa		
d1(	1.364855	0.1000000	70	)=	0.0000000E+00
d1(	1.864855	0.1000000	70	)=	0.1287762
d1(	2.364855	0.1000000	70	)=	0.2575525
d1(	2.864855	0.1000000	70	)=	0.3863288
d1(	3.364855	0.1000000	70	)=	0.5151050
d1(	3.864855	0.1000000	70	)=	0.6438813
d1(	4.364855	0.1000000	70	)=	0.7726575
d1(	4.864855	0.1000000	70	)=	0.9014338
d1(	5.364855	0.1000000	70	)=	1.030210
d1(	5.864855	0.1000000	70	)=	1.158986
d1(	6.364855	0.1000000	70	)=	1.287763
gama(beta=	0.1000000	alfa=	75) >		1.587469
	gama	beta	alfa		
d1(	1.587469	0.1000000	75	)=	0.0000000E+00
d1(	2.087469	0.1000000	75	)=	8.2210816E−02
d1(	2.587469	0.1000000	75	)=	0.1644216
d1(	3.087469	0.1000000	75	)=	0.2466324
d1(	3.587469	0.1000000	75	)=	0.3288433
d1(	4.087469	0.1000000	75	)=	0.4110541
d1(	4.587469	0.1000000	75	)=	0.4932648
d1(	5.087469	0.1000000	75	)=	0.5754756
d1(	5.587469	0.1000000	75	)=	0.6576865
d1(	6.087469	0.1000000	75	)=	0.7398973
d1(	6.587469	0.1000000	75	)=	0.8221080
gama(beta=	0.1000000	alfa=	80) >		2.316863
	gama	beta	alfa		
d1(	2.316863	0.1000000	80	)=	−1.0509909E−08
d1(	2.816863	0.1000000	80	)=	3.7392177E−02
d1(	3.316863	0.1000000	80	)=	7.4784376E−02
d1(	3.816863	0.1000000	80	)=	0.1121766
d1(	4.316863	0.1000000	80	)=	0.1495687
d1(	4.816863	0.1000000	80	)=	0.1869609
d1(	5.316863	0.1000000	80	)=	0.2243531
d1(	5.816863	0.1000000	80	)=	0.2617453
d1(	6.316863	0.1000000	80	)=	0.2991375

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, (d1=ΔL/Rϵ_p).					
d1(	6.816863	0.1000000	80	)=	0.3365296
d1(	7.316863	0.1000000	80	)=	0.3739218
gama(beta=		0.2000000 alfa=	5) >		1.001908
	gama	beta	alfa		
d1(	1.001908	0.2000000	5	)=	0.0000000E+00
d1(	1.501908	0.2000000	5	)=	4.567655
d1(	2.001908	0.2000000	5	)=	9.135310
d1(	2.501908	0.2000000	5	)=	13.70297
d1(	3.001908	0.2000000	5	)=	18.27062
d1(	3.501908	0.2000000	5	)=	22.83828
d1(	4.001908	0.2000000	5	)=	27.40593
d1(	4.501908	0.2000000	5	)=	31.97359
d1(	5.001908	0.2000000	5	)=	36.54124
d1(	5.501908	0.2000000	5	)=	41.10890
d1(	6.001908	0.2000000	5	)=	45.67656
gama(beta=		0.2000000 alfa=	10) >		1.007684
	gama	beta	alfa		
d1(	1.007684	0.2000000	10	)=	0.0000000E+00
d1(	1.507684	0.2000000	10	)=	2.259764
d1(	2.007684	0.2000000	10	)=	4.519529
d1(	2.507684	0.2000000	10	)=	6.779292
d1(	3.007684	0.2000000	10	)=	9.039058
d1(	3.507684	0.2000000	10	)=	11.29882
d1(	4.007684	0.2000000	10	)=	13.55858
d1(	4.507684	0.2000000	10	)=	15.81835
d1(	5.007684	0.2000000	10	)=	18.07811
d1(	5.507684	0.2000000	10	)=	20.33787
d1(	6.007684	0.2000000	10	)=	22.59764
gama(beta=		0.2000000 alfa=	15) >		1.017492
	gama	beta	alfa		
d1(	1.017492	0.2000000	15	)=	0.0000000E+00
d1(	1.517492	0.2000000	15	)=	1.479655
d1(	2.017492	0.2000000	15	)=	2.959310
d1(	2.517492	0.2000000	15	)=	4.438965
d1(	3.017492	0.2000000	15	)=	5.918621
d1(	3.517492	0.2000000	15	)=	7.398275
d1(	4.017492	0.2000000	15	)=	8.877931
d1(	4.517492	0.2000000	15	)=	10.35759
d1(	5.017492	0.2000000	15	)=	11.83724
d1(	5.517492	0.2000000	15	)=	13.31690
d1(	6.017492	0.2000000	15	)=	14.79655
gama(beta=		0.2000000 alfa=	20) >		1.031629
	gama	beta	alfa		
d1(	1.031629	0.2000000	20	)=	0.0000000E+00
d1(	1.531629	0.2000000	20	)=	1.081358
d1(	2.031629	0.2000000	20	)=	2.162717
d1(	2.531629	0.2000000	20	)=	3.244075
d1(	3.031629	0.2000000	20	)=	4.325433
d1(	3.531629	0.2000000	20	)=	5.406792
d1(	4.031629	0.2000000	20	)=	6.488149
d1(	4.531629	0.2000000	20	)=	7.569508
d1(	5.031629	0.2000000	20	)=	8.650867
d1(	5.531629	0.2000000	20	)=	9.732225
d1(	6.031629	0.2000000	20	)=	10.81358
gama(beta=		0.2000000 alfa=	25) >		1.050575
	gama	beta	alfa		
d1(	1.050575	0.2000000	25	)=	0.0000000E+00
d1(	1.550575	0.2000000	25	)=	0.8356334
d1(	2.050575	0.2000000	25	)=	1.671267
d1(	2.550575	0.2000000	25	)=	2.506900
d1(	3.050575	0.2000000	25	)=	3.342533
d1(	3.550575	0.2000000	25	)=	4.178166
d1(	4.050575	0.2000000	25	)=	5.013800
d1(	4.550575	0.2000000	25	)=	5.849433
d1(	5.050575	0.2000000	25	)=	6.685066
d1(	5.550575	0.2000000	25	)=	7.520700
d1(	6.050575	0.2000000	25	)=	8.356333
gama(beta=		0.2000000 alfa=	30) >		1.075072
	gama	beta	alfa		
d1(	1.075072	0.2000000	30	)=	−1.0323828E−07
d1(	1.575072	0.2000000	30	)=	0.6660254

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, (d1=ΔL/Rϵ_p).					
d1(	2.075072	0.2000000	30	)=	1.332051
d1(	2.575072	0.2000000	30	)=	1.998076
d1(	3.075072	0.2000000	30	)=	2.664102
d1(	3.575072	0.2000000	30	)=	3.330127
d1(	4.075072	0.2000000	30	)=	3.996153
d1(	4.575072	0.2000000	30	)=	4.662178
d1(	5.075072	0.2000000	30	)=	5.328203
d1(	5.575072	0.2000000	30	)=	5.994229
d1(	6.075072	0.2000000	30	)=	6.660254
gama(beta=		0.2000000 alfa=	35) >		1.106271
	gama	beta	alfa		
d1(	1.106271	0.2000000	35	)=	0.0000000E+00
d1(	1.606271	0.2000000	35	)=	0.5397293
d1(	2.106271	0.2000000	35	)=	1.079459
d1(	2.606271	0.2000000	35	)=	1.619188
d1(	3.106271	0.2000000	35	)=	2.158918
d1(	3.606271	0.2000000	35	)=	2.698647
d1(	4.106271	0.2000000	35	)=	3.238376
d1(	4.606271	0.2000000	35	)=	3.778105
d1(	5.106271	0.2000000	35	)=	4.317834
d1(	5.606271	0.2000000	35	)=	4.857564
d1(	6.106271	0.2000000	35	)=	5.397293
gama(beta=		0.2000000 alfa=	40) >		1.145987
	gama	beta	alfa		
d1(	1.145987	0.2000000	40	)=	0.0000000E+00
d1(	1.645987	0.2000000	40	)=	0.4403043
d1(	2.145987	0.2000000	40	)=	0.8806087
d1(	2.645987	0.2000000	40	)=	1.320913
d1(	3.145987	0.2000000	40	)=	1.761218
d1(	3.645987	0.2000000	40	)=	2.201522
d1(	4.145987	0.2000000	40	)=	2.641827
d1(	4.645987	0.2000000	40	)=	3.082131
d1(	5.145987	0.2000000	40	)=	3.522435
d1(	5.645987	0.2000000	40	)=	3.962740
d1(	6.145987	0.2000000	40	)=	4.403044
gama(beta=		0.2000000 alfa=	45) >		1.197197
	gama	beta	alfa		
d1(	1.197197	0.2000000	45	)=	0.0000000E+00
d1(	1.697197	0.2000000	45	)=	0.3585786
d1(	2.197197	0.2000000	45	)=	0.7171574
d1(	2.697197	0.2000000	45	)=	1.075736
d1(	3.197197	0.2000000	45	)=	1.434315
d1(	3.697197	0.2000000	45	)=	1.792893
d1(	4.197197	0.2000000	45	)=	2.151472
d1(	4.697197	0.2000000	45	)=	2.510051
d1(	5.197197	0.2000000	45	)=	2.868629
d1(	5.697197	0.2000000	45	)=	3.227208
d1(	6.197197	0.2000000	45	)=	3.585786
gama(beta=		0.2000000 alfa=	50) >		1.265059
	gama	beta	alfa		
d1(	1.265059	0.2000000	50	)=	0.0000000E+00
d1(	1.765059	0.2000000	50	)=	0.2890092
d1(	2.265059	0.2000000	50	)=	0.5780182
d1(	2.765059	0.2000000	50	)=	0.8670272
d1(	3.265059	0.2000000	50	)=	1.156036
d1(	3.765059	0.2000000	50	)=	1.445045
d1(	4.265059	0.2000000	50	)=	1.734055
d1(	4.765059	0.2000000	50	)=	2.023064
d1(	5.265059	0.2000000	50	)=	2.312073
d1(	5.765059	0.2000000	50	)=	2.601082
d1(	6.265059	0.2000000	50	)=	2.890091
gama(beta=		0.2000000 alfa=	55) >		1.359236
	gama	beta	alfa		
d1(	1.359236	0.2000000	55	)=	0.0000000E+00
d1(	1.859236	0.2000000	55	)=	0.2280263
d1(	2.359236	0.2000000	55	)=	0.4560528
d1(	2.859236	0.2000000	55	)=	0.6840791
d1(	3.359236	0.2000000	55	)=	0.9121054
d1(	3.859236	0.2000000	55	)=	1.140132
d1(	4.359236	0.2000000	55	)=	1.368158
d1(	4.859236	0.2000000	55	)=	1.596184
d1(	5.359236	0.2000000	55	)=	1.824211

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, $(d1=\Delta L/R\epsilon_p)$.

d1(	5.859236	0.2000000	55	)=	2.052237
d1(	6.359236	0.2000000	55	)=	2.280263

gama(beta= 0.2000000 alfa= 60) > 1.500000

	gama	beta	alfa		
d1(	1.500000	0.2000000	60	)=	0.0000000E+00
d1(	2.000000	0.2000000	60	)=	0.1732051
d1(	2.500000	0.2000000	60	)=	0.3464102
d1(	3.000000	0.2000000	60	)=	0.5196153
d1(	3.500000	0.2000000	60	)=	0.6928202
d1(	4.000000	0.2000000	60	)=	0.8660252
d1(	4.500000	0.2000000	60	)=	1.039230
d1(	5.000000	0.2000000	60	)=	1.212435
d1(	5.500000	0.2000000	60	)=	1.385640
d1(	6.000000	0.2000000	60	)=	1.558846
d1(	6.500000	0.2000000	60	)=	1.732051

gama(beta= 0.2000000 alfa= 65) > 1.737939

	gama	beta	alfa		
d1(	1.737939	0.2000000	65	)=	0.0000000E+00
d1(	2.237939	0.2000000	65	)=	0.1228161
d1(	2.737939	0.2000000	65	)=	0.2456321
d1(	3.237939	0.2000000	65	)=	0.3684481
d1(	3.737939	0.2000000	65	)=	0.4912642
d1(	4.237939	0.2000000	65	)=	0.6140803
d1(	4.737939	0.2000000	65	)=	0.7368963
d1(	5.237939	0.2000000	65	)=	0.8597122
d1(	5.737939	0.2000000	65	)=	0.9825283
d1(	6.237939	0.2000000	65	)=	1.105344
d1(	6.737939	0.2000000	65	)=	1.228161

gama(beta= 0.2000000 alfa= 70) > 2.243517

	gama	beta	alfa		
d1(	2.243517	0.2000000	70	)=	0.0000000E+00
d1(	2.743517	0.2000000	70	)=	7.5567380E–02
d1(	3.243517	0.2000000	70	)=	0.1511347
d1(	3.743517	0.2000000	70	)=	0.2267021
d1(	4.243517	0.2000000	70	)=	0.3022694
d1(	4.743517	0.2000000	70	)=	0.3778368
d1(	5.243517	0.2000000	70	)=	0.4534041
d1(	5.743517	0.2000000	70	)=	0.5289715
d1(	6.243517	0.2000000	70	)=	0.6045388
d1(	6.743517	0.2000000	70	)=	0.6801062
d1(	7.243517	0.2000000	70	)=	0.7556735

gama(beta= 0.2000000 alfa= 75) > 4.172484

	gama	beta	alfa		
d1(	4.172484	0.2000000	75	)=	0.0000000E+00
d1(	4.672484	0.2000000	75	)=	3.0446989E–02
d1(	5.172484	0.2000000	75	)=	6.0893979E–02
d1(	5.672484	0.2000000	75	)=	9.1340967E–02
d1(	6.172484	0.2000000	75	)=	0.1217880
d1(	6.672484	0.2000000	75	)=	0.1522349
d1(	7.172484	0.2000000	75	)=	0.1826819
d1(	7.672484	0.2000000	75	)=	0.2131289
d1(	8.172484	0.2000000	75	)=	0.2435759
d1(	8.672484	0.2000000	75	)=	0.2740229
d1(	9.172484	0.2000000	75	)=	0.3044699

gama(beta= 0.3000000 alfa= 5) > 1.003273

	gama	beta	alfa		
d1(	1.003273	0.3000000	5	)=	0.0000000E+00
d1(	1.503273	0.3000000	5	)=	3.993970
d1(	2.003273	0.3000000	5	)=	7.987939
d1(	2.503273	0.3000000	5	)=	11.98191
d1(	3.003273	0.3000000	5	)=	15.97588
d1(	3.503273	0.3000000	5	)=	19.96985
d1(	4.003273	0.3000000	5	)=	23.96382
d1(	4.503273	0.3000000	5	)=	27.95779
d1(	5.003273	0.3000000	5	)=	31.95176
d1(	5.503273	0.3000000	5	)=	35.94573
d1(	6.003273	0.3000000	5	)=	39.93970

gama(beta= 0.3000000 alfa= 10) > 1.013210

	gama	beta	alfa		
d1(	1.013210	0.3000000	10	)=	0.0000000E+00
d1(	1.513210	0.3000000	10	)=	1.971826

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, $(d1=\Delta L/R\epsilon_p)$.

d1(	2.013210	0.3000000	10	)=	3.943652
d1(	2.513210	0.3000000	10	)=	5.915477
d1(	3.013210	0.3000000	10	)=	7.887302
d1(	3.513210	0.3000000	10	)=	9.859128
d1(	4.013210	0.3000000	10	)=	11.83095
d1(	4.513210	0.3000000	10	)=	13.80278
d1(	5.013210	0.3000000	10	)=	15.77460
d1(	5.513210	0.3000000	10	)=	17.74643
d1(	6.013210	0.3000000	10	)=	19.71825

gama(beta= 0.3000000 alfa= 15) > 1.030178

	gama	beta	alfa		
d1(	1.030178	0.3000000	15	)=	0.0000000E+00
d1(	1.530178	0.3000000	15	)=	1.286470
d1(	2.030178	0.3000000	15	)=	2.572940
d1(	2.530178	0.3000000	15	)=	3.859410
d1(	3.030178	0.3000000	15	)=	5.145880
d1(	3.530178	0.3000000	15	)=	6.432350
d1(	4.030178	0.3000000	15	)=	7.718821
d1(	4.530178	0.3000000	15	)=	9.005290
d1(	5.030178	0.3000000	15	)=	10.29176
d1(	5.530178	0.3000000	15	)=	11.57823
d1(	6.030178	0.3000000	15	)=	12.86470

gama(beta= 0.3000000 alfa= 20) > 1.054860

	gama	beta	alfa		
d1(	1.054860	0.3000000	20	)=	0.0000000E+00
d1(	1.554860	0.3000000	20	)=	0.9351683
d1(	2.054860	0.3000000	20	)=	1.870337
d1(	2.554860	0.3000000	20	)=	2.805505
d1(	3.054860	0.3000000	20	)=	3.740673
d1(	3.554860	0.3000000	20	)=	4.675841
d1(	4.054860	0.3000000	20	)=	5.611008
d1(	4.554860	0.3000000	20	)=	6.546177
d1(	5.054860	0.3000000	20	)=	7.481345
d1(	5.554860	0.3000000	20	)=	8.416512
d1(	6.054860	0.3000000	20	)=	9.351681

gama(beta= 0.3000000 alfa= 25) > 1.088374

	gama	beta	alfa		
d1(	1.088374	0.3000000	25	)=	0.0000000E+00
d1(	1.588374	0.3000000	25	)=	0.7173234
d1(	2.088374	0.3000000	25	)=	1.434647
d1(	2.588374	0.3000000	25	)=	2.151970
d1(	3.088374	0.3000000	25	)=	2.869293
d1(	3.588374	0.3000000	25	)=	3.586617
d1(	4.088374	0.3000000	25	)=	4.303940
d1(	4.588374	0.3000000	25	)=	5.021263
d1(	5.088374	0.3000000	25	)=	5.738586
d1(	5.588374	0.3000000	25	)=	6.455910
d1(	6.088374	0.3000000	25	)=	7.173233

gama(beta= 0.3000000 alfa= 30) > 1.132503

	gama	beta	alfa		
d1(	1.132503	0.3000000	30	)=	0.0000000E+00
d1(	1.632503	0.3000000	30	)=	0.5660253
d1(	2.132503	0.3000000	30	)=	1.132051
d1(	2.632503	0.3000000	30	)=	1.698076
d1(	3.132503	0.3000000	30	)=	2.264102
d1(	3.632503	0.3000000	30	)=	2.830127
d1(	4.132503	0.3000000	30	)=	3.396153
d1(	4.632503	0.3000000	30	)=	3.962178
d1(	5.132503	0.3000000	30	)=	4.528203
d1(	5.632503	0.3000000	30	)=	5.094229
d1(	6.132503	0.3000000	30	)=	5.660254

gama(beta= 0.3000000 alfa= 35) > 1.190112

	gama	beta	alfa		
d1(	1.190112	0.3000000	35	)=	0.0000000E+00
d1(	1.690112	0.3000000	35	)=	0.4525571
d1(	2.190112	0.3000000	35	)=	0.9051141
d1(	2.690112	0.3000000	35	)=	1.357671
d1(	3.190112	0.3000000	35	)=	1.810228
d1(	3.690112	0.3000000	35	)=	2.262785
d1(	4.190112	0.3000000	35	)=	2.715343
d1(	4.690112	0.3000000	35	)=	3.167900
d1(	5.190112	0.3000000	35	)=	3.620456

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ($d1=\Delta L/R\epsilon_p$).

d1(	5.690112	0.3000000	35	)= 4.073013
d1(	6.190112	0.3000000	35	)= 4.525570
gama(beta=	0.3000000 alfa=		40) >	1.265968
	gama	beta	alfa	
d1(	1.265968	0.3000000	40	)= 0.0000000E+00
d1(	1.765968	0.3000000	40	)= 0.3625183
d1(	2.265968	0.3000000	40	)= 0.7250366
d1(	2.765968	0.3000000	40	)= 1.087555
d1(	3.265968	0.3000000	40	)= 1.450073
d1(	3.765968	0.3000000	40	)= 1.812591
d1(	4.265968	0.3000000	40	)= 2.175110
d1(	4.765968	0.3000000	40	)= 2.537628
d1(	5.265968	0.3000000	40	)= 2.900146
d1(	5.765968	0.3000000	40	)= 3.262665
d1(	6.265968	0.3000000	40	)= 3.625183
gama(beta=	0.3000000 alfa=		45) >	1.368454
	gama	beta	alfa	
d1(	1.368454	0.3000000	45	)= 0.0000000E+00
d1(	1.868454	0.3000000	45	)= 0.2878680
d1(	2.368454	0.3000000	45	)= 0.5757360
d1(	2.868454	0.3000000	45	)= 0.8636041
d1(	3.368454	0.3000000	45	)= 1.151472
d1(	3.868454	0.3000000	45	)= 1.439340
d1(	4.368454	0.3000000	45	)= 1.727208
d1(	4.868454	0.3000000	45	)= 2.015076
d1(	5.368454	0.3000000	45	)= 2.302944
d1(	5.868454	0.3000000	45	)= 2.590812
d1(	6.368454	0.3000000	45	)= 2.878680
gama(beta=	0.3000000 alfa=		50) >	1.513575
	gama	beta	alfa	
d1(	1.513575	0.3000000	50	)= 0.0000000E+00
d1(	2.013575	0.3000000	50	)= 0.2237388
d1(	2.513575	0.3000000	50	)= 0.4474775
d1(	3.013575	0.3000000	50	)= 0.6712162
d1(	3.513575	0.3000000	50	)= 0.8949549
d1(	4.013576	0.3000000	50	)= 1.118694
d1(	4.513576	0.3000000	50	)= 1.342432
d1(	5.013576	0.3000000	50	)= 1.566171
d1(	5.513576	0.3000000	50	)= 1.789910
d1(	6.013576	0.3000000	50	)= 2.013649
d1(	6.513576	0.3000000	50	)= 2.237387
gama(beta=	0.3000000 alfa=		55) >	1.735820
	gama	beta	alfa	
d1(	1.735820	0.3000000	55	)= 0.0000000E+00
d1(	2.235820	0.3000000	55	)= 0.1669876
d1(	2.735820	0.3000000	55	)= 0.3339752
d1(	3.235820	0.3000000	55	)= 0.5009628
d1(	3.735820	0.3000000	55	)= 0.6679505
d1(	4.235820	0.3000000	55	)= 0.8349380
d1(	4.735820	0.3000000	55	)= 1.001926
d1(	5.235820	0.3000000	55	)= 1.168913
d1(	5.735820	0.3000000	55	)= 1.335901
d1(	6.235820	0.3000000	55	)= 1.502888
d1(	6.735820	0.3000000	55	)= 1.669876
gama(beta=	0.3000000 alfa=		60) >	2.125000
	gama	beta	alfa	
d1(	2.125000	0.3000000	60	)= 0.0000000E+00
d1(	2.625000	0.3000000	60	)= 0.1154701
d1(	3.125000	0.3000000	60	)= 0.2309401
d1(	3.625000	0.3000000	60	)= 0.3464102
d1(	4.125000	0.3000000	60	)= 0.4618802
d1(	4.625000	0.3000000	60	)= 0.5773503
d1(	5.125000	0.3000000	60	)= 0.6928203
d1(	5.625000	0.3000000	60	)= 0.8082904
d1(	6.125000	0.3000000	60	)= 0.9237605
d1(	6.625000	0.3000000	60	)= 1.039231
d1(	7.125000	0.3000000	60	)= 1.154701
gama(beta=	0.3000000 alfa=		65) >	3.009636
	gama	beta	alfa	
d1(	3.009636	0.3000000	65	)= 0.0000000E+00
d1(	3.509636	0.3000000	65	)= 6.7647174E-02

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ($d1=\Delta L/R\epsilon_p$).

d1(	4.009636	0.3000000	65	)= 0.1352943
d1(	4.509636	0.3000000	65	)= 0.2029415
d1(	5.009636	0.3000000	65	)= 0.2705886
d1(	5.509636	0.3000000	65	)= 0.3382358
d1(	6.009636	0.3000000	65	)= 0.4058830
d1(	6.509636	0.3000000	65	)= 0.4735300
d1(	7.009636	0.3000000	65	)= 0.5411772
d1(	7.509636	0.3000000	65	)= 0.6088244
d1(	8.009637	0.3000000	65	)= 0.6764715
gama(beta=	0.3000000 alfa=		70) >	7.304273
	gama	beta	alfa	
d1(	7.304273	0.3000000	70	)= 0.0000000E+00
d1(	7.804273	0.3000000	70	)= 2.2358468E-02
d1(	8.304274	0.3000000	70	)= 4.4716977E-02
d1(	8.804274	0.3000000	70	)= 6.7075446E-02
d1(	9.304274	0.3000000	70	)= 8.9433916E-02
d1(	9.804274	0.3000000	70	)= 0.1117924
d1(	10.30427	0.3000000	70	)= 0.1341508
d1(	10.80427	0.3000000	70	)= 0.1565093
d1(	11.30427	0.3000000	70	)= 0.1788678
d1(	11.80427	0.3000000	70	)= 0.2012262
d1(	12.30427	0.3000000	70	)= 0.2235847
gama(beta=	0.4000000 alfa=		5) >	1.005096
	gama	beta	alfa	
d1(	1.005096	0.4000000	5	)= 0.0000000E+00
d1(	1.505096	0.4000000	5	)= 3.420284
d1(	2.005096	0.4000000	5	)= 6.840568
d1(	2.505096	0.4000000	5	)= 10.26085
d1(	3.005096	0.4000000	5	)= 13.68113
d1(	3.505096	0.4000000	5	)= 17.10142
d1(	4.005096	0.4000000	5	)= 20.52170
d1(	4.505096	0.4000000	5	)= 23.94199
d1(	5.005096	0.4000000	5	)= 27.36227
d1(	5.505096	0.4000000	5	)= 30.78255
d1(	6.005096	0.4000000	5	)= 34.20284
gama(beta=	0.4000000 alfa=		10) >	1.020625
	gama	beta	alfa	
d1(	1.020625	0.4000000	10	)= 0.0000000E+00
d1(	1.520625	0.4000000	10	)= 1.683887
d1(	2.020625	0.4000000	10	)= 3.367775
d1(	2.520625	0.4000000	10	)= 5.051661
d1(	3.020625	0.4000000	10	)= 6.735548
d1(	3.520625	0.4000000	10	)= 8.419435
d1(	4.020625	0.4000000	10	)= 10.10332
d1(	4.520625	0.4000000	10	)= 11.78721
d1(	5.020625	0.4000000	10	)= 13.47109
d1(	5.520625	0.4000000	10	)= 15.15498
d1(	6.020625	0.4000000	10	)= 16.83887
gama(beta=	0.4000000 alfa=		15) >	1.047347
	gama	beta	alfa	
d1(	1.047347	0.4000000	15	)= 0.0000000E+00
d1(	1.547347	0.4000000	15	)= 1.093285
d1(	2.047347	0.4000000	15	)= 2.186569
d1(	2.547347	0.4000000	15	)= 3.279854
d1(	3.047347	0.4000000	15	)= 4.373139
d1(	3.547347	0.4000000	15	)= 5.466424
d1(	4.047347	0.4000000	15	)= 6.559709
d1(	4.547347	0.4000000	15	)= 7.652993
d1(	5.047347	0.4000000	15	)= 8.746278
d1(	5.547347	0.4000000	15	)= 9.839563
d1(	6.047347	0.4000000	15	)= 10.93285
gama(beta=	0.4000000 alfa=		20) >	1.086700
	gama	beta	alfa	
d1(	1.086700	0.4000000	20	)= 0.0000000E+00
d1(	1.586700	0.4000000	20	)= 0.7889779
d1(	2.086700	0.4000000	20	)= 1.577956
d1(	2.586700	0.4000000	20	)= 2.366934
d1(	3.086700	0.4000000	20	)= 3.155912
d1(	3.586700	0.4000000	20	)= 3.944890
d1(	4.086699	0.4000000	20	)= 4.733867
d1(	4.586699	0.4000000	20	)= 5.522845
d1(	5.086699	0.4000000	20	)= 6.311823

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, $(d1 = \Delta L/R\epsilon_p)$.					
d1(	5.586699	0.4000000	20	)=	7.100801
d1(	6.086699	0.4000000	20	)=	7.889779
gama(beta=	0.4000000	alfa=	25) >		1.141105
	gama	beta	alfa		
d1(	1.141105	0.4000000	25	)=	0.0000000E+00
d1(	1.641105	0.4000000	25	)=	0.5990134
d1(	2.141105	0.4000000	25	)=	1.198027
d1(	2.641105	0.4000000	25	)=	1.797040
d1(	3.141105	0.4000000	25	)=	2.396053
d1(	3.641105	0.4000000	25	)=	2.995066
d1(	4.141105	0.4000000	25	)=	3.594079
d1(	4.641105	0.4000000	25	)=	4.193092
d1(	5.141105	0.4000000	25	)=	4.792106
d1(	5.641105	0.4000000	25	)=	5.391119
d1(	6.141105	0.4000000	25	)=	5.990132
gama(beta=	0.4000000	alfa=	30) >		1.214581
	gama	beta	alfa		
d1(	1.214581	0.4000000	30	)=	0.0000000E+00
d1(	1.714581	0.4000000	30	)=	0.4660254
d1(	2.214581	0.4000000	30	)=	0.9320508
d1(	2.714581	0.4000000	30	)=	1.398076
d1(	3.214581	0.4000000	30	)=	1.864102
d1(	3.714581	0.4000000	30	)=	2.330127
d1(	4.214581	0.4000000	30	)=	2.796153
d1(	4.714581	0.4000000	30	)=	3.262178
d1(	5.214581	0.4000000	30	)=	3.728203
d1(	5.714581	0.4000000	30	)=	4.194229
d1(	6.214581	0.4000000	30	)=	4.660254
gama(beta=	0.4000000	alfa=	35) >		1.313958
	gama	beta	alfa		
d1(	1.313958	0.4000000	35	)=	0.0000000E+00
d1(	1.813958	0.4000000	35	)=	0.3653848
d1(	2.313958	0.4000000	35	)=	0.7307695
d1(	2.813958	0.4000000	35	)=	1.096154
d1(	3.313958	0.4000000	35	)=	1.461539
d1(	3.813958	0.4000000	35	)=	1.826923
d1(	4.313958	0.4000000	35	)=	2.192308
d1(	4.813958	0.4000000	35	)=	2.557693
d1(	5.313958	0.4000000	35	)=	2.923077
d1(	5.813958	0.4000000	35	)=	3.288462
d1(	6.313958	0.4000000	35	)=	3.653847
gama(beta=	0.4000000	alfa=	40) >		1.451504
	gama	beta	alfa		
d1(	1.451504	0.4000000	40	)=	0.0000000E+00
d1(	1.951504	0.4000000	40	)=	0.2847320
d1(	2.451504	0.4000000	40	)=	0.5694641
d1(	2.951504	0.4000000	40	)=	0.8541961
d1(	3.451504	0.4000000	40	)=	1.138928
d1(	3.951504	0.4000000	40	)=	1.423660
d1(	4.451504	0.4000000	40	)=	1.708392
d1(	4.951504	0.4000000	40	)=	1.993124
d1(	5.451504	0.4000000	40	)=	2.277856
d1(	5.951504	0.4000000	40	)=	2.562588
d1(	6.451504	0.4000000	40	)=	2.847321
gama(beta=	0.4000000	alfa=	45) >		1.651239
	gama	beta	alfa		
d1(	1.651239	0.4000000	45	)=	0.0000000E+00
d1(	2.151239	0.4000000	45	)=	0.2171572
d1(	2.651239	0.4000000	45	)=	0.4343146
d1(	3.151239	0.4000000	45	)=	0.6514719
d1(	3.651239	0.4000000	45	)=	0.8686291
d1(	4.151239	0.4000000	45	)=	1.085786
d1(	4.651239	0.4000000	45	)=	1.302943
d1(	5.151239	0.4000000	45	)=	1.520101
d1(	5.651239	0.4000000	45	)=	1.737258
d1(	6.151239	0.4000000	45	)=	1.954415
d1(	6.651239	0.4000000	45	)=	2.171573
gama(beta=	0.4000000	alfa=	50) >		1.966811
	gama	beta	alfa		
d1(	1.966811	0.4000000	50	)=	0.0000000E+00
d1(	2.466811	0.4000000	50	)=	0.1584684

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, $(d1 = \Delta L/R\epsilon_p)$.					
d1(	2.966811	0.4000000	50	)=	0.3169367
d1(	3.466811	0.4000000	50	)=	0.4754050
d1(	3.966811	0.4000000	50	)=	0.6338733
d1(	4.466811	0.4000000	50	)=	0.7923417
d1(	4.966811	0.4000000	50	)=	0.9508100
d1(	5.466811	0.4000000	50	)=	1.109279
d1(	5.966811	0.4000000	50	)=	1.267747
d1(	6.466811	0.4000000	50	)=	1.426215
d1(	6.966811	0.4000000	50	)=	1.584683
gama(beta=	0.4000000	alfa=	55) >		2.546316
	gama	beta	alfa		
d1(	2.546316	0.4000000	55	)=	0.0000000E+00
d1(	3.046316	0.4000000	55	)=	0.1059489
d1(	3.546316	0.4000000	55	)=	0.2118977
d1(	4.046316	0.4000000	55	)=	0.3178467
d1(	4.546316	0.4000000	55	)=	0.4237956
d1(	5.046316	0.4000000	55	)=	0.5297443
d1(	5.546316	0.4000000	55	)=	0.6356933
d1(	6.046316	0.4000000	55	)=	0.7416422
d1(	6.546316	0.4000000	55	)=	0.8475911
d1(	7.046316	0.4000000	55	)=	0.9535400
d1(	7.546316	0.4000000	55	)=	1.059489
gama(beta=	0.4000000	alfa=	60) >		4.000001
	gama	beta	alfa		
d1(	4.000001	0.4000000	60	)=	0.0000000E+00
d1(	4.500001	0.4000000	60	)=	5.7735037E-02
d1(	5.000001	0.4000000	60	)=	0.1154700
d1(	5.500001	0.4000000	60	)=	0.1732050
d1(	6.000001	0.4000000	60	)=	0.2309400
d1(	6.500001	0.4000000	60	)=	0.2886750
d1(	7.000001	0.4000000	60	)=	0.3464100
d1(	7.500001	0.4000000	60	)=	0.4041451
d1(	8.000002	0.4000000	60	)=	0.4618801
d1(	8.500002	0.4000000	60	)=	0.5196151
d1(	9.000002	0.4000000	60	)=	0.5773501
gama(beta=	0.4000000	alfa=	65) >		15.52622
	gama	beta	alfa		
d1(	15.52622	0.4000000	65	)=	0.0000000E+00
d1(	16.02622	0.4000000	65	)=	1.2478273E-02
d1(	16.52622	0.4000000	65	)=	2.4956491E-02
d1(	17.02622	0.4000000	65	)=	3.7434764E-02
d1(	17.52622	0.4000000	65	)=	4.9912982E-02
d1(	18.02622	0.4000000	65	)=	6.2391199E-02
d1(	18.52622	0.4000000	65	)=	7.4869417E-02
d1(	19.02622	0.4000000	65	)=	8.7347694E-02
d1(	19.52622	0.4000000	65	)=	9.9825911E-02
d1(	20.02622	0.4000000	65	)=	0.1123041
d1(	20.52622	0.4000000	65	)=	0.1247824
gama(beta=	0.5000000	alfa=	5) >		1.007654
	gama	beta	alfa		
d1(	1.007654	0.5000000	5	)=	0.0000000E+00
d1(	1.507654	0.5000000	5	)=	2.846598
d1(	2.007654	0.5000000	5	)=	5.693197
d1(	2.507654	0.5000000	5	)=	8.539796
d1(	3.007654	0.5000000	5	)=	11.38639
d1(	3.507654	0.5000000	5	)=	14.23299
d1(	4.007654	0.5000000	5	)=	17.07959
d1(	4.507654	0.5000000	5	)=	19.92619
d1(	5.007654	0.5000000	5	)=	22.77279
d1(	5.507654	0.5000000	5	)=	25.61938
d1(	6.007654	0.5000000	5	)=	28.46598
gama(beta=	0.5000000	alfa=	10) >		1.031099
	gama	beta	alfa		
d1(	1.031099	0.5000000	10	)=	0.0000000E+00
d1(	1.531099	0.5000000	10	)=	1.395948
d1(	2.031099	0.5000000	10	)=	2.791897
d1(	2.531099	0.5000000	10	)=	4.187845
d1(	3.031099	0.5000000	10	)=	5.583793
d1(	3.531099	0.5000000	10	)=	6.979742
d1(	4.031099	0.5000000	10	)=	8.375691
d1(	4.531099	0.5000000	10	)=	9.771640
d1(	5.031099	0.5000000	10	)=	11.16759

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, (d1=ΔL/Rϵ_p).

d1(	5.531099	0.5000000	10	)=	12.56354
d1(	6.031099	0.5000000	10	)=	13.95948

gama(beta= 0.5000000 alfa= 15) > 1.071886

	gama	beta	alfa		
d1(	1.071886	0.5000000	15	)=	0.0000000E+00
d1(	1.571886	0.5000000	15	)=	0.9000998
d1(	2.071886	0.5000000	15	)=	1.800200
d1(	2.571886	0.5000000	15	)=	2.700299
d1(	3.071886	0.5000000	15	)=	3.600399
d1(	3.571886	0.5000000	15	)=	4.500498
d1(	4.071886	0.5000000	15	)=	5.400597
d1(	4.571886	0.5000000	15	)=	6.300696
d1(	5.071886	0.5000000	15	)=	7.200796
d1(	5.571886	0.5000000	15	)=	8.100896
d1(	6.071886	0.5000000	15	)=	9.000996

gama(beta= 0.5000000 alfa= 20) > 1.133022

	gama	beta	alfa		
d1(	1.133022	0.5000000	20	)=	0.0000000E+00
d1(	1.633022	0.5000000	20	)=	0.6427878
d1(	2.133022	0.5000000	20	)=	1.285576
d1(	2.633022	0.5000000	20	)=	1.928363
d1(	3.133022	0.5000000	20	)=	2.571151
d1(	3.633022	0.5000000	20	)=	3.213938
d1(	4.133022	0.5000000	20	)=	3.856726
d1(	4.633022	0.5000000	20	)=	4.499513
d1(	5.133022	0.5000000	20	)=	5.142301
d1(	5.633022	0.5000000	20	)=	5.785089
d1(	6.133022	0.5000000	20	)=	6.427876

gama(beta= 0.5000000 alfa= 25) > 1.219792

	gama	beta	alfa		
d1(	1.219792	0.5000000	25	)=	0.0000000E+00
d1(	1.719792	0.5000000	25	)=	0.4807031
d1(	2.219792	0.5000000	25	)=	0.9614062
d1(	2.719792	0.5000000	25	)=	1.442109
d1(	3.219792	0.5000000	25	)=	1.922812
d1(	3.719792	0.5000000	25	)=	2.403515
d1(	4.219792	0.5000000	25	)=	2.884219
d1(	4.719792	0.5000000	25	)=	3.364922
d1(	5.219792	0.5000000	25	)=	3.845624
d1(	5.719792	0.5000000	25	)=	4.326327
d1(	6.219792	0.5000000	25	)=	4.807031

gama(beta= 0.5000000 alfa= 30) > 1.341506

	gama	beta	alfa		
d1(	1.341506	0.5000000	30	)=	0.0000000E+00
d1(	1.841506	0.5000000	30	)=	0.3660255
d1(	2.341506	0.5000000	30	)=	0.7320511
d1(	2.841506	0.5000000	30	)=	1.098076
d1(	3.341506	0.5000000	30	)=	1.464102
d1(	3.841506	0.5000000	30	)=	1.830127
d1(	4.341506	0.5000000	30	)=	2.196153
d1(	4.841506	0.5000000	30	)=	2.562178
d1(	5.341506	0.5000000	30	)=	2.928203
d1(	5.841506	0.5000000	30	)=	3.294229
d1(	6.341506	0.5000000	30	)=	3.660254

gama(beta= 0.5000000 alfa= 35) > 1.515412

	gama	beta	alfa		
d1(	1.515412	0.5000000	35	)=	0.0000000E+00
d1(	2.015413	0.5000000	35	)=	0.2782125
d1(	2.515413	0.5000000	35	)=	0.5564247
d1(	3.015413	0.5000000	35	)=	0.8346372
d1(	3.515413	0.5000000	35	)=	1.112849
d1(	4.015412	0.5000000	35	)=	1.391062
d1(	4.515412	0.5000000	35	)=	1.669274
d1(	5.015412	0.5000000	35	)=	1.947486
d1(	5.515412	0.5000000	35	)=	2.225699
d1(	6.015412	0.5000000	35	)=	2.503911
d1(	6.515412	0.5000000	35	)=	2.782123

gama(beta= 0.5000000 alfa= 40) > 1.776517

	gama	beta	alfa		
d1(	1.776517	0.5000000	40	)=	0.0000000E+00
d1(	2.276517	0.5000000	40	)=	0.2069459

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, (d1=ΔL/Rϵ_p).

d1(	2.776517	0.5000000	40	)=	0.4138919
d1(	3.276517	0.5000000	40	)=	0.6208376
d1(	3.776517	0.5000000	40	)=	0.8277834
d1(	4.276517	0.5000000	40	)=	1.034729
d1(	4.776517	0.5000000	40	)=	1.241675
d1(	5.276517	0.5000000	40	)=	1.448621
d1(	5.776517	0.5000000	40	)=	1.655567
d1(	6.276517	0.5000000	40	)=	1.862513
d1(	6.776517	0.5000000	40	)=	2.069459

gama(beta= 0.5000000 alfa= 45) > 2.207107

	gama	beta	alfa		
d1(	2.207107	0.5000000	45	)=	0.0000000E+00
d1(	2.707107	0.5000000	45	)=	0.1464467
d1(	3.207107	0.5000000	45	)=	0.2928933
d1(	3.707107	0.5000000	45	)=	0.4393399
d1(	4.207107	0.5000000	45	)=	0.5857866
d1(	4.707107	0.5000000	45	)=	0.7322332
d1(	5.207107	0.5000000	45	)=	0.8786799
d1(	5.707107	0.5000000	45	)=	1.025126
d1(	6.207107	0.5000000	45	)=	1.171573
d1(	6.707107	0.5000000	45	)=	1.318020
d1(	7.207107	0.5000000	45	)=	1.464466

gama(beta= 0.5000000 alfa= 50) > 3.054885

	gama	beta	alfa		
d1(	3.054885	0.5000000	50	)=	0.0000000E+00
d1(	3.554885	0.5000000	50	)=	9.3198024E–02
d1(	4.054885	0.5000000	50	)=	0.1863960
d1(	4.554885	0.5000000	50	)=	0.2795941
d1(	5.054885	0.5000000	50	)=	0.3727920
d1(	5.554885	0.5000000	50	)=	0.4659900
d1(	6.054885	0.5000000	50	)=	0.5591879
d1(	6.554885	0.5000000	50	)=	0.6523860
d1(	7.054885	0.5000000	50	)=	0.7455839
d1(	7.554885	0.5000000	50	)=	0.8387819
d1(	8.054885	0.5000000	50	)=	0.9319797

gama(beta= 0.5000000 alfa= 55) > 5.559950

	gama	beta	alfa		
d1(	5.559950	0.5000000	55	)=	0.0000000E+00
d1(	6.059950	0.5000000	55	)=	4.4910204E–02
d1(	6.559950	0.5000000	55	)=	8.9820325E–02
d1(	7.059950	0.5000000	55	)=	0.1347304
d1(	7.559950	0.5000000	55	)=	0.1796406
d1(	8.059951	0.5000000	55	)=	0.2245508
d1(	8.559951	0.5000000	55	)=	0.2694609
d1(	9.059951	0.5000000	55	)=	0.3143710
d1(	9.559951	0.5000000	55	)=	0.3592812
d1(	10.05995	0.5000000	55	)=	0.4041913
d1(	10.55995	0.5000000	55	)=	0.4491014

gama(beta= 0.6000000 alfa= 5) > 1.011504

	gama	beta	alfa		
d1(	1.011504	0.6000000	5	)=	0.0000000E+00
d1(	1.511504	0.6000000	5	)=	2.272913
d1(	2.011504	0.6000000	5	)=	4.545825
d1(	2.511504	0.6000000	5	)=	6.818738
d1(	3.011504	0.6000000	5	)=	9.091650
d1(	3.511504	0.6000000	5	)=	11.36456
d1(	4.011504	0.6000000	5	)=	13.63748
d1(	4.511504	0.6000000	5	)=	15.91039
d1(	5.011504	0.6000000	5	)=	18.18330
d1(	5.511504	0.6000000	5	)=	20.45621
d1(	6.011504	0.6000000	5	)=	22.72912

gama(beta= 0.6000000 alfa= 10) > 1.047016

	gama	beta	alfa		
d1(	1.047016	0.6000000	10	)=	0.0000000E+00
d1(	1.547016	0.6000000	10	)=	1.108010
d1(	2.047016	0.6000000	10	)=	2.216020
d1(	2.547016	0.6000000	10	)=	3.324029
d1(	3.047016	0.6000000	10	)=	4.432040
d1(	3.547016	0.6000000	10	)=	5.540050
d1(	4.047016	0.6000000	10	)=	6.648058
d1(	4.547016	0.6000000	10	)=	7.756068
d1(	5.047016	0.6000000	10	)=	8.864079

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ($d1=\Delta L/R\epsilon_p$).

d1(	5.547016	0.6000000	10	)=	9.972089
d1(	6.047016	0.6000000	10	)=	11.08010

gama(beta= 0.6000000 alfa= 15) > 1.109838

	gama	beta	alfa		
d1(	1.109838	0.6000000	15	)=	0.0000000E+00
d1(	1.609838	0.6000000	15	)=	0.7069143
d1(	2.109838	0.6000000	15	)=	1.413829
d1(	2.609838	0.6000000	15	)=	2.120744
d1(	3.109838	0.6000000	15	)=	2.827658
d1(	3.609838	0.6000000	15	)=	3.534573
d1(	4.109838	0.6000000	15	)=	4.241487
d1(	4.609838	0.6000000	15	)=	4.948401
d1(	5.109838	0.6000000	15	)=	5.655315
d1(	5.609838	0.6000000	15	)=	6.362230
d1(	6.109838	0.6000000	15	)=	7.069144

gama(beta= 0.6000000 alfa= 20) > 1.206618

	gama	beta	alfa		
d1(	1.206618	0.6000000	20	)=	0.0000000E+00
d1(	1.706618	0.6000000	20	)=	0.4965974
d1(	2.206618	0.6000000	20	)=	0.9931949
d1(	2.706618	0.6000000	20	)=	1.489792
d1(	3.206618	0.6000000	20	)=	1.986390
d1(	3.706618	0.6000000	20	)=	2.482987
d1(	4.206618	0.6000000	20	)=	2.979584
d1(	4.706618	0.6000000	20	)=	3.476182
d1(	5.206618	0.6000000	20	)=	3.972780
d1(	5.706618	0.6000000	20	)=	4.469377
d1(	6.206618	0.6000000	20	)=	4.965974

gama(beta= 0.6000000 alfa= 25) > 1.349856

	gama	beta	alfa		
d1(	1.349856	0.6000000	25	)=	0.0000000E+00
d1(	1.849856	0.6000000	25	)=	0.3623931
d1(	2.349856	0.6000000	25	)=	0.7247862
d1(	2.849856	0.6000000	25	)=	1.087179
d1(	3.349856	0.6000000	25	)=	1.449572
d1(	3.849856	0.6000000	25	)=	1.811965
d1(	4.349856	0.6000000	25	)=	2.174359
d1(	4.849856	0.6000000	25	)=	2.536751
d1(	5.349856	0.6000000	25	)=	2.899144
d1(	5.849856	0.6000000	25	)=	3.261538
d1(	6.349856	0.6000000	25	)=	3.623930

gama(beta= 0.6000000 alfa= 30) > 1.563856

	gama	beta	alfa		
d1(	1.563856	0.6000000	30	)=	0.0000000E+00
d1(	2.063856	0.6000000	30	)=	0.2660254
d1(	2.563856	0.6000000	30	)=	0.5320508
d1(	3.063856	0.6000000	30	)=	0.7980763
d1(	3.563856	0.6000000	30	)=	1.064102
d1(	4.063856	0.6000000	30	)=	1.330127
d1(	4.563856	0.6000000	30	)=	1.596153
d1(	5.063856	0.6000000	30	)=	1.862178
d1(	5.563856	0.6000000	30	)=	2.128203
d1(	6.063856	0.6000000	30	)=	2.394229
d1(	6.563856	0.6000000	30	)=	2.660254

gama(beta= 0.6000000 alfa= 35) > 1.900716

	gama	beta	alfa		
d1(	1.900716	0.6000000	35	)=	0.0000000E+00
d1(	2.400717	0.6000000	35	)=	0.1910401
d1(	2.900717	0.6000000	35	)=	0.3820800
d1(	3.400717	0.6000000	35	)=	0.5731202
d1(	3.900717	0.6000000	35	)=	0.7641601
d1(	4.400716	0.6000000	35	)=	0.9552000
d1(	4.900716	0.6000000	35	)=	1.146240
d1(	5.400716	0.6000000	35	)=	1.337280
d1(	5.900716	0.6000000	35	)=	1.528320
d1(	6.400716	0.6000000	35	)=	1.719360
d1(	6.900716	0.6000000	35	)=	1.910400

gama(beta= 0.6000000 alfa= 40) > 2.493007

	gama	beta	alfa		
d1(	2.493007	0.6000000	40	)=	0.0000000E+00
d1(	2.993007	0.6000000	40	)=	0.1291597

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, ($d1=\Delta L/R\epsilon_p$).

d1(	3.493007	0.6000000	40	)=	0.2583195
d1(	3.993007	0.6000000	40	)=	0.3874791
d1(	4.493007	0.6000000	40	)=	0.5166388
d1(	4.993007	0.6000000	40	)=	0.6457986
d1(	5.493007	0.6000000	40	)=	0.7749582
d1(	5.993007	0.6000000	40	)=	0.9041179
d1(	6.493007	0.6000000	40	)=	1.033278
d1(	6.993007	0.6000000	40	)=	1.162437
d1(	7.493007	0.6000000	40	)=	1.291597

gama(beta= 0.6000000 alfa= 45) > 3.800942

	gama	beta	alfa		
d1(	3.800942	0.6000000	45	)=	0.0000000E+00
d1(	4.300942	0.6000000	45	)=	7.5736046E–02
d1(	4.800942	0.6000000	45	)=	0.1514720
d1(	5.300942	0.6000000	45	)=	0.2272079
d1(	5.800942	0.6000000	45	)=	0.3029439
d1(	6.300942	0.6000000	45	)=	0.3786799
d1(	6.800942	0.6000000	45	)=	0.4544158
d1(	7.300942	0.6000000	45	)=	0.5301518
d1(	7.800942	0.6000000	45	)=	0.6058878
d1(	8.300942	0.6000000	45	)=	0.6816237
d1(	8.800942	0.6000000	45	)=	0.7573596

gama(beta= 0.6000000 alfa= 50) > 9.228890

	gama	beta	alfa		
d1(	9.228890	0.6000000	50	)=	0.0000000E+00
d1(	9.728890	0.6000000	50	)=	2.7927648E–02
d1(	10.22889	0.6000000	50	)=	5.5855297E–02
d1(	10.72889	0.6000000	50	)=	8.3782844E–02
d1(	11.22889	0.6000000	50	)=	0.1117105
d1(	11.72889	0.6000000	50	)=	0.1396381
d1(	12.22889	0.6000000	50	)=	0.1675658
d1(	12.72889	0.6000000	50	)=	0.1954933
d1(	13.22889	0.6000000	50	)=	0.2234210
d1(	13.72889	0.6000000	50	)=	0.2513486
d1(	14.22889	0.6000000	50	)=	0.2792763

gama(beta= 0.7000000 alfa= 5) > 1.017952

	gama	beta	alfa		
d1(	1.017952	0.7000000	5	)=	0.0000000E+00
d1(	1.517952	0.7000000	5	)=	1.699228
d1(	2.017952	0.7000000	5	)=	3.398454
d1(	2.517952	0.7000000	5	)=	5.097681
d1(	3.017952	0.7000000	5	)=	6.796908
d1(	3.517952	0.7000000	5	)=	8.496135
d1(	4.017952	0.7000000	5	)=	10.19536
d1(	4.517952	0.7000000	5	)=	11.89459
d1(	5.017952	0.7000000	5	)=	13.59381
d1(	5.517952	0.7000000	5	)=	15.29304
d1(	6.017952	0.7000000	5	)=	16.99227

gama(beta= 0.7000000 alfa= 10) > 1.074112

	gama	beta	alfa		
d1(	1.074112	0.7000000	10	)=	0.0000000E+00
d1(	1.574112	0.7000000	10	)=	0.8200716
d1(	2.074112	0.7000000	10	)=	1.640143
d1(	2.574112	0.7000000	10	)=	2.460214
d1(	3.074112	0.7000000	10	)=	3.280286
d1(	3.574112	0.7000000	10	)=	4.100357
d1(	4.074112	0.7000000	10	)=	4.920428
d1(	4.574112	0.7000000	10	)=	5.740499
d1(	5.074112	0.7000000	10	)=	6.560570
d1(	5.574112	0.7000000	10	)=	7.380642
d1(	6.074112	0.7000000	10	)=	8.200713

gama(beta= 0.7000000 alfa= 15) > 1.176332

	gama	beta	alfa		
d1(	1.176332	0.7000000	15	)=	0.0000000E+00
d1(	1.676332	0.7000000	15	)=	0.5137293
d1(	2.176332	0.7000000	15	)=	1.027459
d1(	2.676332	0.7000000	15	)=	1.541188
d1(	3.176332	0.7000000	15	)=	2.054917
d1(	3.676332	0.7000000	15	)=	2.568646
d1(	4.176332	0.7000000	15	)=	3.082376
d1(	4.676332	0.7000000	15	)=	3.596105
d1(	5.176332	0.7000000	15	)=	4.109834

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, (d1=ΔL/Rϵ_p).

d1(	5.676332	0.7000000	15	)=	4.623564
d1(	6.176332	0.7000000	15	)=	5.137293
gama(beta=	0.7000000 alfa=		20) >		1.341623
	gama	beta	alfa		
d1(	1.341623	0.7000000	20	)=	0.0000000E+00
d1(	1.841623	0.7000000	20	)=	0.3504074
d1(	2.341623	0.7000000	20	)=	0.7008147
d1(	2.841623	0.7000000	20	)=	1.051222
d1(	3.341623	0.7000000	20	)=	1.401629
d1(	3.841623	0.7000000	20	)=	1.752036
d1(	4.341623	0.7000000	20	)=	2.102443
d1(	4.841623	0.7000000	20	)=	2.452851
d1(	5.341623	0.7000000	20	)=	2.803258
d1(	5.841623	0.7000000	20	)=	3.153665
d1(	6.341623	0.7000000	20	)=	3.504072
gama(beta=	0.7000000 alfa=		25) >		1.606009
	gama	beta	alfa		
d1(	1.606009	0.7000000	25	)=	0.0000000E+00
d1(	2.106009	0.7000000	25	)=	0.2440831
d1(	2.606009	0.7000000	25	)=	0.4881659
d1(	3.106009	0.7000000	25	)=	0.7322490
d1(	3.606009	0.7000000	25	)=	0.9763318
d1(	4.106009	0.7000000	25	)=	1.220415
d1(	4.606009	0.7000000	25	)=	1.464498
d1(	5.106009	0.7000000	25	)=	1.708581
d1(	5.606009	0.7000000	25	)=	1.952664
d1(	6.106009	0.7000000	25	)=	2.196746
d1(	6.606009	0.7000000	25	)=	2.440830
gama(beta=	0.7000000 alfa=		30) >		2.054056
	gama	beta	alfa		
d1(	2.054056	0.7000000	30	)=	0.0000000E+00
d1(	2.554056	0.7000000	30	)=	0.1660255
d1(	3.054056	0.7000000	30	)=	0.3320508
d1(	3.554056	0.7000000	30	)=	0.4980763
d1(	4.054056	0.7000000	30	)=	0.6641017
d1(	4.554056	0.7000000	30	)=	0.8301272
d1(	5.054056	0.7000000	30	)=	0.9961525
d1(	5.554056	0.7000000	30	)=	1.162178
d1(	6.054056	0.7000000	30	)=	1.328203
d1(	6.554056	0.7000000	30	)=	1.494229
d1(	7.054056	0.7000000	30	)=	1.660254
gama(beta=	0.7000000 alfa=		35) >		2.932765
	gama	beta	alfa		
d1(	2.932765	0.7000000	35	)=	0.0000000E+00
d1(	3.432765	0.7000000	35	)=	0.1038678
d1(	3.932765	0.7000000	35	)=	0.2077354
d1(	4.432765	0.7000000	35	)=	0.3116030
d1(	4.932765	0.7000000	35	)=	0.4154705
d1(	5.432765	0.7000000	35	)=	0.5193383
d1(	5.932765	0.7000000	35	)=	0.6232059
d1(	6.432765	0.7000000	35	)=	0.7270735
d1(	6.932765	0.7000000	35	)=	0.8309411
d1(	7.432765	0.7000000	35	)=	0.9348087
d1(	7.932765	0.7000000	35	)=	1.038677
gama(beta=	0.7000000 alfa=		40) >		5.379220
	gama	beta	alfa		
d1(	5.379220	0.7000000	40	)=	0.0000000E+00
d1(	5.879220	0.7000000	40	)=	5.1373534E-02
d1(	6.379220	0.7000000	40	)=	0.1027469
d1(	6.879220	0.7000000	40	)=	0.1541205
d1(	7.379220	0.7000000	40	)=	0.2054938
d1(	7.879220	0.7000000	40	)=	0.2568674
d1(	8.379220	0.7000000	40	)=	0.3082408
d1(	8.879220	0.7000000	40	)=	0.3596143
d1(	9.379220	0.7000000	40	)=	0.4109877
d1(	9.879220	0.7000000	40	)=	0.4623612
d1(	10.37922	0.7000000	40	)=	0.5137346
gama(beta=	0.7000000 alfa=		45) >		50.24860
	gama	beta	alfa		
d1(	50.24860	0.7000000	45	)=	0.0000000E+00
d1(	50.74860	0.7000000	45	)=	5.0252676E-03

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, (d1=ΔL/Rϵ_p).

d1(	51.24860	0.7000000	45	)=	1.0050535E-02
d1(	51.74860	0.7000000	45	)=	1.5075803E-02
d1(	52.24860	0.7000000	45	)=	2.0101070E-02
d1(	52.74860	0.7000000	45	)=	2.5126338E-02
d1(	53.24860	0.7000000	45	)=	3.0151606E-02
d1(	53.74860	0.7000000	45	)=	3.5176873E-02
d1(	54.24860	0.7000000	45	)=	4.0202141E-02
d1(	54.74860	0.7000000	45	)=	4.5227408E-02
d1(	55.24860	0.7000000	45	)=	5.0252676E-02
gama(beta=	0.8000000 alfa=		5) >		1.030974
	gama	beta	alfa		
d1(	1.030974	0.8000000	5	)=	0.0000000E+00
d1(	1.530974	0.8000000	5	)=	1.125542
d1(	2.030974	0.8000000	5	)=	2.251082
d1(	2.530974	0.8000000	5	)=	3.376623
d1(	3.030974	0.8000000	5	)=	4.502163
d1(	3.530974	0.8000000	5	)=	5.627705
d1(	4.030974	0.8000000	5	)=	6.753245
d1(	4.530974	0.8000000	5	)=	7.878787
d1(	5.030974	0.8000000	5	)=	9.004327
d1(	5.530974	0.8000000	5	)=	10.12987
d1(	6.030974	0.8000000	5	)=	11.25541
gama(beta=	0.8000000 alfa=		10) >		1.130530
	gama	beta	alfa		
d1(	1.130530	0.8000000	10	)=	0.0000000E+00
d1(	1.630530	0.8000000	10	)=	0.5321329
d1(	2.130530	0.8000000	10	)=	1.064265
d1(	2.630530	0.8000000	10	)=	1.596398
d1(	3.130530	0.8000000	10	)=	2.128531
d1(	3.630530	0.8000000	10	)=	2.660663
d1(	4.130530	0.8000000	10	)=	3.192796
d1(	4.630530	0.8000000	10	)=	3.724929
d1(	5.130530	0.8000000	10	)=	4.257061
d1(	5.630530	0.8000000	10	)=	4.789194
d1(	6.130530	0.8000000	10	)=	5.321326
gama(beta=	0.8000000 alfa=		15) >		1.322975
	gama	beta	alfa		
d1(	1.322975	0.8000000	15	)=	0.0000000E+00
d1(	1.822975	0.8000000	15	)=	0.3205443
d1(	2.322975	0.8000000	15	)=	0.6410881
d1(	2.822975	0.8000000	15	)=	0.9616324
d1(	3.322975	0.8000000	15	)=	1.282176
d1(	3.822975	0.8000000	15	)=	1.602720
d1(	4.322975	0.8000000	15	)=	1.923264
d1(	4.822975	0.8000000	15	)=	2.243809
d1(	5.322975	0.8000000	15	)=	2.564352
d1(	5.822975	0.8000000	15	)=	2.884897
d1(	6.322975	0.8000000	15	)=	3.205441
gama(beta=	0.8000000 alfa=		20) >		1.669916
	gama	beta	alfa		
d1(	1.669916	0.8000000	20	)=	0.0000000E+00
d1(	2.169916	0.8000000	20	)=	0.2042170
d1(	2.669916	0.8000000	20	)=	0.4084340
d1(	3.169916	0.8000000	20	)=	0.6126506
d1(	3.669916	0.8000000	20	)=	0.8168676
d1(	4.169916	0.8000000	20	)=	1.021085
d1(	4.669916	0.8000000	20	)=	1.225302
d1(	5.169916	0.8000000	20	)=	1.429518
d1(	5.669916	0.8000000	20	)=	1.633735
d1(	6.169916	0.8000000	20	)=	1.837952
d1(	6.669916	0.8000000	20	)=	2.042169
gama(beta=	0.8000000 alfa=		25) >		2.344067
	gama	beta	alfa		
d1(	2.344067	0.8000000	25	)=	0.0000000E+00
d1(	2.844067	0.8000000	25	)=	0.1257728
d1(	3.344067	0.8000000	25	)=	0.2515459
d1(	3.844067	0.8000000	25	)=	0.3773187
d1(	4.344068	0.8000000	25	)=	0.5030918
d1(	4.844068	0.8000000	25	)=	0.6288645
d1(	5.344068	0.8000000	25	)=	0.7546374
d1(	5.844068	0.8000000	25	)=	0.8804101
d1(	6.344068	0.8000000	25	)=	1.006183

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, $(d1=\Delta L/R\epsilon_p)$.

d1(	6.844068	0.8000000	25	)=	1.131956
d1(	7.344068	0.8000000	25	)=	1.257729
gama(beta=	0.8000000	alfa=	30) >		4.029140
	gama	beta	alfa		
d1(	4.029140	0.8000000	30	)=	0.0000000E+00
d1(	4.529140	0.8000000	30	)=	6.6025421E–02
d1(	5.029140	0.8000000	30	)=	0.1320508
d1(	5.529140	0.8000000	30	)=	0.1980761
d1(	6.029140	0.8000000	30	)=	0.2641015
d1(	6.529140	0.8000000	30	)=	0.3301269
d1(	7.029140	0.8000000	30	)=	0.3961523
d1(	7.529140	0.8000000	30	)=	0.4621775
d1(	8.029140	0.8000000	30	)=	0.5282030
d1(	8.529140	0.8000000	30	)=	0.5942284
d1(	9.029140	0.8000000	30	)=	0.6602538
gama(beta=	0.8000000	alfa=	35) >		14.74223
	gama	beta	alfa		
d1(	14.74223	0.8000000	35	)=	0.0000000E+00
d1(	15.24223	0.8000000	35	)=	1.6695250E–02
d1(	15.74223	0.8000000	35	)=	3.3390671E–02
d1(	16.24223	0.8000000	35	)=	5.0085921E–02
d1(	16.74223	0.8000000	35	)=	6.6781171E–02
d1(	17.24223	0.8000000	35	)=	8.3476588E–02
d1(	17.74223	0.8000000	35	)=	0.1001718
d1(	18.24223	0.8000000	35	)=	0.1168671
d1(	18.74223	0.8000000	35	)=	0.1335623
d1(	19.24223	0.8000000	35	)=	0.1502578
d1(	19.74223	0.8000000	35	)=	0.1669530
gama(beta=	0.9000000	alfa=	5) >		1.071069
	gama	beta	alfa		
d1(	1.071069	0.9000000	5	)=	0.0000000E+00
d1(	1.571069	0.9000000	5	)=	0.5518552
d1(	2.071069	0.9000000	5	)=	1.103712
d1(	2.571069	0.9000000	5	)=	1.655567
d1(	3.071069	0.9000000	5	)=	2.207422
d1(	3.571069	0.9000000	5	)=	2.759278
d1(	4.071069	0.9000000	5	)=	3.311134
d1(	4.571069	0.9000000	5	)=	3.862989
d1(	5.071069	0.9000000	5	)=	4.414845
d1(	5.571069	0.9000000	5	)=	4.966701
d1(	6.071069	0.9000000	5	)=	5.518556
gama(beta=	0.9000000	alfa=	10) >		1.319999
	gama	beta	alfa		
d1(	1.319999	0.9000000	10	)=	0.0000000E+00
d1(	1.819999	0.9000000	10	)=	0.2441943
d1(	2.319999	0.9000000	10	)=	0.4883885
d1(	2.819999	0.9000000	10	)=	0.7325828
d1(	3.319999	0.9000000	10	)=	0.9767771
d1(	3.819999	0.9000000	10	)=	1.220971
d1(	4.319999	0.9000000	10	)=	1.465166
d1(	4.819999	0.9000000	10	)=	1.709360
d1(	5.319999	0.9000000	10	)=	1.953554
d1(	5.819999	0.9000000	10	)=	2.197748
d1(	6.319999	0.9000000	10	)=	2.441943
gama(beta=	0.9000000	alfa=	15) >		1.914492
	gama	beta	alfa		
d1(	1.914492	0.9000000	15	)=	0.0000000E+00
d1(	2.414492	0.9000000	15	)=	0.1273588
d1(	2.914492	0.9000000	15	)=	0.2547180
d1(	3.414492	0.9000000	15	)=	0.3820768
d1(	3.914492	0.9000000	15	)=	0.5094356
d1(	4.414492	0.9000000	15	)=	0.6367944
d1(	4.914492	0.9000000	15	)=	0.7641537
d1(	5.414492	0.9000000	15	)=	0.8915125
d1(	5.914492	0.9000000	15	)=	1.018871
d1(	6.414492	0.9000000	15	)=	1.146230
d1(	6.914492	0.9000000	15	)=	1.273589
gama(beta=	0.9000000	alfa=	20) >		3.652381
	gama	beta	alfa		
d1(	3.652381	0.9000000	20	)=	0.0000000E+00
d1(	4.152381	0.9000000	20	)=	5.8026921E–02

TABLE 1-continued

Design Parameters for CSSC Tube Fitting, $(d1=\Delta L/R\epsilon_p)$.

d1(	4.652381	0.9000000	20	)=	0.1160535
d1(	5.152381	0.9000000	20	)=	0.1740804
d1(	5.652381	0.9000000	20	)=	0.2321070
d1(	6.152381	0.9000000	20	)=	0.2901340
d1(	6.652381	0.9000000	20	)=	0.3481605
d1(	7.152381	0.9000000	20	)=	0.4061875
d1(	7.652381	0.9000000	20	)=	0.4642141
d1(	8.152381	0.9000000	20	)=	0.5222410
d1(	8.652381	0.9000000	20	)=	0.5802675
gama(beta=	0.9000000	alfa=	25) >		26.48351
	gama	beta	alfa		
d1(	26.48351	0.9000000	25	)=	0.0000000E+00
d1(	26.98351	0.9000000	25	)=	7.4627930E–03
d1(	27.48351	0.9000000	25	)=	1.4925586E–02
d1(	27.98351	0.9000000	25	)=	2.2388378E–02
d1(	28.48351	0.9000000	25	)=	2.9851172E–02
d1(	28.98351	0.9000000	25	)=	3.7313964E–02
d1(	29.48351	0.9000000	25	)=	4.4776756E–02
d1(	29.98351	0.9000000	25	)=	5.2239552E–02
d1(	30.48351	0.9000000	25	)=	5.9702344E–02
d1(	30.98351	0.9000000	25	)=	6.7165136E–02
d1(	31.48351	0.9000000	25	)=	7.4627928E–02 ^Z

I claim:

1. A cryogenic tube seal comprising:

a coupling member comprising a first axisymmetric sloped contact surface;

sealing means comprising a second axisymmetric contact surface, made of a material having a larger coefficient of thermal expansion than said first contact surface, and having a shape which is complementary to that of said first contact surface whereby when said second contact surface is brought into secured contact with said first contact surface at ambient temperature, the contact between the two surfaces is a sealed sloped engagement creating sloped-surface sealing which allows thermal contraction and expansion of said coupling member and said sealing means under temperature cycling from room temperature to temperatures at least as low as about 77K while maintaining sloped-surface sealing between said coupling member and said sealing means and not causing or resulting in the inelastic deformation of either of said surfaces, such that said surfaces can be repeatedly separated and re-engaged wherein said re-engagement is a sealed engagement; and

means for bringing said first contact surface and said second contact surface into secured contact.

2. The seal of claim 1 wherein said first contact surface is on a first coupling member and said second contact surface is on a second coupling member.

3. The seal of claim 1 wherein said second contact surface is a spacer.

4. The seal of claim 3 wherein said spacer is an O-ring.

5. The seal of claim 3 wherein said spacer comprises a female-flared contact surface.

6. The seal of claim 3 wherein said spacer comprises a male an-flared contact surface.

7. The seal of claim 3 wherein a cross section through said spacer is H-shaped, whereby the sloped seal is maintained by contraction of said spacer below ambient temperatures or expansion by said spacer above ambient temperatures.

8. The seal of claim **2** wherein said means comprises a housing nut made of a material having a larger coefficient of thermal expansion than said first contact surface.

9. The seal of claim **3** wherein said means comprises a housing nut made of a material having a larger coefficient of thermal expansion than said first contact surface.

10. The seal of claim **7** wherein said means comprises a housing nut made of a material having a smaller coefficient of thermal expansion than does said spacer.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,620,187

DATED : April 15, 1997

INVENTOR(S) : Lin X. Jia

It is certified that error appears in the above-indentified patent and that said Letters Patent is hereby corrected as shown below:

Column 1: line 23: "J.F.X. Space Center" should read --J.F.K. Space Center--;

line 29: "between taro" should read --between two--;

line 31: "In pan," should read --In part,--;

line 59: "sealing ting must" should read --sealing ring must--;

line 61: "sealing ting is" should read --sealing ring is--;

line 63: "the sealing ting" should read --the sealing ring--.

Column 2: line 27: "known in the an," should read --known in the art--;

lines 36&37: "serf-sealing" should read --self-sealing--.

Column 3: line 60: "pans of contracting serf-sealing" should read --parts of contracting self-sealing--.

Column 4: line 7: "into homing nut" should read --into housing nut--;

line 21: "all pans" should read --all parts--;

line 23: "pans of" should read --parts of--.

Column 6: line 1: "a is the" should read --α is the--;

line 21: "fi is the radius" should read --β is the radius--;

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,620,187

DATED : April 15, 1997

INVENTOR(S) : Lin X. Jia

It is certified that error appears in the above-indentified patent and that said Letters Patent is hereby corrected as shown below:

Column 6: lines 3&4: "spacer, γ_o" should read --spacer, w/R. γ_o--;

line 5: "tube ends $\gamma_5(\gamma_h=\epsilon_h/\epsilon_p)$" should read --tube ends. $\gamma_h(\gamma_h=\epsilon_h/\epsilon_p)$--

line 25: "serf-sealing" should read --self-sealing--;

line 37: "mating pans before" should read --mating parts before--.

Column 7: line 41: "a depends" should read --α depends--;

line 42: "value of fi depends" should read --value of β depends--;

line 51: "and $\epsilon_{op}=0.06\%$" should read --and $\epsilon_p=0.06\%$--;

line 64: "Concept of" should read --concept of--.

Column 8: line 17: "serf-sealing" should read --self-sealing--;

Column 9, line 24: "a fight seal" should read --a tight seal--;

line 52: "serf-sealing" should read --self-sealing--;

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,620,187

DATED : April 15, 1997

INVENTOR(S) : Lin X. Jia

It is certified that error appears in the above-indentified patent and that said Letters Patent is hereby corrected as shown below:

Column 9, line 64: "serf-sealing" should read--self-sealing--.

Signed and Sealed this

Twelfth Day of August, 1997

Attest:

Bruce Lehman

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks